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The utility of information a method of evaluation

Larry Lee Mengel
Lehigh University

THE UTILITY OF INFORMATION

A METHOD OF EVALUATION

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Larry Lee Mengel

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Date

Wallace J. Richardson
Professor in Charge

[signature]
Head of the Department

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ABSTRACT

The fundamental relationships among the design parameters of an information system and the utility of the information that a system produces are analyzed in an effort to develop a methodology for measuring the utility of information. The approach that was employed is based on the hypothesis that the utility of information is a function of three basic aspects of an information system—the quality, the quantity, and the timeliness of the information provided. The utility of the information is defined as a measure of the effectiveness with which the information can be employed to attain the objectives of the using organization. The method that has been proposed employs the technique of simulating the operations of a small industrial organization with a well-defined organizational structure. The simulation model included both the normal operational aspects of this experimental environment and the influences that would be created by a proposed information system improvement. The design parameters of the proposed information system were included as input variables that could be varied to allow the model to represent several different information system configurations.

The simulation model was used to conduct a 4 by 3 factorial experiment to identify the effects of the changes

in the parameters on the utility that the organization could expect to derive from similar changes in its actual information system. As a result of this experiment it was concluded that improved quality (or accuracy), increased quantity, or improved timeliness of information do not automatically result in more useful information. The experiment indicated that there are significant interactions among the various parameters which can cause a degradation of the utility of information where one would normally expect the utility to be improved. The interpretation of these results is that an apriori assumption of the value of an information system improvement is not necessarily justified unless the functional relationships among the design parameters and the utility of information have been thoroughly considered.

BACKGROUND

Information systems technology has been developed to the point that it is now within the realm of possibility to consider the design of an information system which would provide a business manager with complete, accurate, and instantaneous information about all aspects of his business environment. Assuming, of course, that someone is willing and able to pay the cost. In discussing such a system Aron states,

> Although it is possible to question the economy of doing all these things automatically, it should be clear that an integrated data system can be designed to make them possible.[1]

The combination of this potential and the current modus operandi of some business organizations could lead to some very ineffective system designs. Schoderbek states that, "Some companies operate under the erroneous assumption that the more information available to the manager, the better must be the decision reached."[2]

This "more information—better decisions" philosophy has been held in check in the past because of technological

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[1] J. D. Aron, "Information Systems in Perspective," Computing Surveys, December 1967, p. 219.

[2] Peter P. Schoderbek, Management Systems, New York: John Wiley and Sons, Inc., 1967, p. 43.

limitations. However, as these limitations are stripped away the question of economy will become more and more pertinent. It seems obvious that there is a limit on the amount of sophistication that can be built, economically, into an information system. Therefore, the question arises as to where this limit occurs and how one proceeds to identify it.

One contemporary approach to system justification is to attempt to compare the cost of a proposed information system improvement with the cost of the existing system. The improvement is justified, if the cost of the improved system is the lesser.[3] This has probably been a very pragmatic approach to the justification of system improvements, because the limitations of technology have prohibited extravagances in system sophistication in the past. However, these limitations are being rapidly eliminated.

There is evidence that emphasis is now being placed on a comparison between information value and information cost. Much of the literature on the design of management information systems recognizes the importance of designing a system to be compatable with the "needs" of the user.[4]

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[3] Jay Forrester, Industrial Dynamics, Cambridge, Massachusetts: M.I.T. Press, 1968, p. 427.

[4] Robert H. Gregory and Richard L. Van Horn, Automatic Data-Processing, 2nd ed., Belmont, California: Wadsworth Publishing Co., 1969, p. 566; J. W. Konvalinka and H. G. Trentin, "Management Information Systems," Management Systems, edited by Peter P. Schoderbek, New York: John Wiley and Sons, Inc., 1967, p. 172; Aron, "Information Systems," p. 213.

Some authors allude to the fact that there is a relationship between information utility and "user need," but they fail to pursue a definition of that relationship.[5] Discussing the criteria to be applied in planning a management information system, Moravec poses the following question as a requirement to be met in determining how much information should be provided by a system: "Does the cost difference for data exceed the marginal utility of the information to the user?"[6] Unfortunately, he does not attempt to define how this "marginal utility" is to be measured.

A probable explanation for the failure of management information scientists to pursue this problem is that they usually attempt to equate utility with the need for information without proper regard for the degree of need involved. The problem is further complicated by the fact that it is difficult for a manager to adequately identify his information needs.

> Most MIS designers "determine" what information is needed by asking managers what information they would like to have. This is based on the assumption that managers know what information they need and [that they] want it.[7]

This assumption is seldom correct. A manager's conception of information need is likely to be deficient for the purposes

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[5] Ibid., p. 223.

[6] F. A. Moravec, "Basic Concepts for Designing a Fundamental Information System," Management Systems, edited by Peter P. Schoderbek, New York: John Wiley and Sons, Inc., 1967, p. 135.

[7] Russell L. Ackoff, "Management Misinformation Systems," Management Sciences, December 1967, p. B-149.

of information system design. Moravec feels that their conception of need will be based upon "habitual modes" which can include either too much information or else the wrong kinds of information.[8] Daniel attributes a different cause, ". . . he [the manager] may find it difficult to be articulate because the organization of his company is not clearly defined."[9] Recognizing the inability of managers to specify, accurately, what their information needs are, it is highly unlikely that a manager's subjective evaluation of the utility associated with his needs could be a meaningful standard for measuring the rate of return on a costly system improvement or for designing specific features into a system. It is even less likely that a system designer's evaluation would be adequate, because he would have even less intuition about the value of information to a particular organization.

The solution is to eliminate the subjectivity which is involved in the evaluation. This can be accomplished by developing a method for qualifying the degree of need which will reduce or eliminate the subjectivity that is currently unavoidable in the justification of system design. Forrester emphasizes this problem:

> For lack of any real measure of the value of information, this justification is almost never made on the basis of the relationship between information cost and information value.[10]

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[8]Moravec, "Designing Information Systems," p. 130.

[9]Ronald D. Daniel, "Management Information Crisis," <u>Management Information Series Reprints from Harvard Business Review</u>, September-October 1961, p. 93.

[10]Forrester, <u>Industrial Dynamics</u>, p. 427.

If there were a technique for measuring the value of information, it would be possible to determine quantitatively how much improvement a system can be subjected to before the incremental return no longer justifies the added investment. The problem is more than a mere academic exercise. The president of Brandon Systems, an independent software supplier, claims that ". . . easily 60% of the American companies using computers aren't getting anywhere near this [13%] return on their investment."[11] This is not to say that the improper evaluation of information requirements is the only reason for this failure, but it is certainly a contributor.

The "past cost versus proposed cost" approach to system justification cannot answer the question of how much one should invest in improving an information system.[12] The answer can only be found by comparing investment costs with what some authors loosely call "benefits from the information,"[13] but which I shall refer to as the "utility of improved information." The implication here is that there exists a functional relationship between an increment of investment in system improvement and some additional utility obtained from having improved information. The cost of the investment is a matter of standard accounting techniques.

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[11]George J. Berkwit, "Up-Tight with Software," Dun's Review, October 1968, p. 128.

[12]Gregory and Van Horn, Data-Processing, p. 574.

[13]Ibid., p. 580.

The problem requiring investigation is that of ". . . quantifying these hithertofore 'intangible' benefits."[14]

It is evident that the development of a "cost versus utility" methodology for evaluating systems design is a complex problem. The practitioners have recognized a need for this type of approach, but have not developed the techniques to make it possible. There are techniques available for measuring cost and for comparing cost with utility. The missing link in the problem is a method for measuring utility.

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[14] Robert V. Head, "Management Information Systems: A Critical Appraisal," Datamation, May 1967, p. 27.

OBJECTIVE

The objective of this thesis is to identify the functional relationship between the utility of information and the parameters of a business environment which influence the value that can be derived from information. The accomplishment of this objective is the essential first step in the development of a general methodology for evaluating information systems improvements.

INTRODUCTION TO THE PROBLEM

The purpose of this section is to develop a hypothesis about the utility of information based upon the various theories and approaches of contemporary practitioners. Several theories have evolved through the process of trial and error, but none has gained universal acceptance because each dwells on limited aspects of the total problem. In spite of their shortcomings, each theory is the product of practical experience with the problem and offers useful insights into the true nature of information utility. The relevant aspects of these theories and approaches provide the basis for the hypothesis to be investigated in this thesis.

A common approach to the evaluation of information utility is the "past cost versus proposed cost" method which was mentioned previously. This approach has the implied premise that information is always worth more than the cost of obtaining it. The premise would appear invalid but, considering the history of management information systems applications, it has been pragmatic at least.

The primary costs of early applications were incurred through computerization of business functions that were of unquestionable importance. Financial records and payroll systems, which were absolutely essential to the existence of a business organization, were the first targets. The assumption of a very high value in such cases was valid, because without the information the organization could not have legally existed. The only necessary consideration, therefore, was the reduction of collecting and processing costs. In those cases, where the assumption was valid, the "past cost versus proposed cost" method was, likewise, valid.

As these essential business functions are automated and management's attention is turned toward production control, inventory management, sales forecasting, and similar functions, this method loses some of its effectiveness. The concept of reducing information system costs may come into direct conflict with the primary aim of a business organization, which is to make money. The capabilities of electronic data processing equipment have opened many new fields of application which were impossible before. This suggests that it may be advantageous to increase costs in some areas and expand the profit-making potential rather than reduce cost in order to save money. Furthermore, some types of information and the rationale for using them are rendered obsolete by the new technology. In such cases, it may be advantageous to eliminate completely the collecting and processing of some types of information rather than reduce the cost of same. Unless one is dealing with unproductive information that has the singular purpose of satisfying legal or traditional requirements, the arbitrary assumption of value is unjustifiable. The effect of inaccuracies in these assumptions can work two ways—to perpetuate the obsolete or to retard the profitable.

An alternate approach to evaluating information utility is inferred by Blumenthal in his outline of the preliminary analysis phase of information system planning. He states that one of the points to be included in a systems proposal is, "A qualitative statement of the benefits expected, in order of importance (cost avoidance, improved service, improved timeliness, increased accuracy, etc.)."[15] His implication is that these factors are, in some manner, a valid measure of the "benefits" to be derived from a proposed system improvement. It is also implied that a business manager, who is responsible for approving the investment required to make the improvement, will be able to make a sound judgment based on these factors. The premise of Blumenthal's method is that the utility of information is enhanced by improving service, timeliness, and accuracy and by reducing cost. In many cases this premise has practical merit, but it is not universally true.

"Cost avoidance" and "improved service" are desirable characteristics of an information system change, but they do not necessarily result in more useful information. "Cost avoidance" is similar to the "past cost versus proposed cost" method and is subject to the same limitations as an approach to system evaluation. "Improved service" is an

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[15]Scherman C. Blumenthal, Management Information Systems: A Framework for Planning and Development, Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1969, p. 116.

ambiguous characteristic. It is a potential catchall for benefits that are difficult to define and, consequently, may not exist. To be a useful measure of utility, "improved service" requires a precise definition that discriminates it from other system characteristics, such as timeliness. Even with such a definition it is applicable only in situations where the organization is in the business of providing a service.

In some situations "improved timeliness" and "increased accuracy" may result in more useful information, but there is a problem of diminishing returns due to the interaction between these two parameters. Consider a production manager who issues a production schedule every Monday morning. Assume that he uses a report of projected sales in the preparation of his schedule and that he must have this report by the preceding Friday morning in order to give it proper consideration in preparing his schedule. If the sales estimate is prepared as of Friday morning, it will be accurate and up to date, but it will arrive too late for the manager to use it properly. If it is prepared on Thursday, it will arrive on time, but it will suffer from inaccuracies. The degree of influence that these factors may have is not important at this point—questions of magnitude will be considered later. The point illustrated by this example is that there is an interaction between timeliness and accuracy. An improvement in one may cause a degradation in the other. It may be undesirable, if not impossible, to increase both of these factors simultaneously.

A critical review of information value theories has been made by Gregory and Van Horn. They divide these theories into three categories: "intangibles, cost outlay, and managerial use."[16] Their critique suggests several aspects of a business environment which contribute to the utility of information.

The theories of "intangibles" recognize that at least a part, and possibly all, of the utility derived from an item of information is not subject to qualitative measurement. Some authors argue that, ". . . most of the benefits of a management information system are of this intangible nature."[17] By definition an intangible cannot be measured, but there are dangers in the arbitrary assignment of value to these benefits. Many of the intangible benefits are a function of the catastrophies which can be averted by being able to take proper preventive action. The possibilities for exaggeration are numerous. Consider the information that a government collects to avert involvement in a war. If it succeeds in preventing a war there is no way to measure the value of the information. In the first place, it would be virtually impossible to prove that a war had been averted as a result of some item of information. Secondly, if a war did not occur, it is difficult to assess the costs that have been saved. Finally, it would be a gross exaggeration to assume that such a government could afford to pay for the

[16] Gregory and Van Horn, Data-Processing, p. 572.

[17] Head, "Management Information Systems," p. 27.

information in an amount equal to some arbitrary cost that might be assigned. In a normal business environment the problems are not so extreme, but problems of evaluating intangibles exist on a smaller scale. It is difficult to evaluate the cost of an event that has been averted, regardless of its potential magnitude.

Schoderbek recommends a cautious approach when dealing with the "intangible" component of information value.

> Much of the so-called information utilized in management systems today enjoys a "sacred definiteness" which is subject to wide ranges of both human and institutional error. Valueless data has, in many instances, been accepted simply because of an emotional investment on the part of practitioners who have traditionally treated such data in their routine operations.[18]

The question of "intangible" value can be grossly inflated by "emotional investments" which tend to obscure the true value of a commodity. On the other hand, the failure to consider intangible value might result in the failure to collect and process some information that would be worthwhile, if the intangibles were properly considered.[19]

A pragmatic approach to the evaluation of intangibles is suggested by Morrison. He would, first, determine how much the information will cost, and then "ask whether it is worth it."[20] The advantage of this approach is that at least

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[18] Schoderbek, Management Systems, p. 44.

[19] Gregory and Van Horn, Data-Processing, p. 572.

[20] J. Morison, "Summary of the Panel Discussion on Meeting Operational Requirements," Information Systems Workshop, Washington, D.C.: Spartan Books, 1962, p. 70.

one concrete element (cost) is entered into an otherwise totally subjective evaluation. The application of traditional utility theory in this context may also be useful. By developing "personal utility functions"[21] for the intangible components of information value it may be possible to develop a frame of reference for combining tangible and intangible components.

The theories of "cost outlay" include the concepts of "past cost versus proposed cost" and of "cost avoidance." These theories take the conservative approach of reducing cost and ignore the question of utility.

The theories of "managerial use" are based on the premise that information has value to an organization in an amount equal to the penalty incurred by the organization for not having the information available. In theory, the value of a particular item of information could be determined by withholding the information from its users and then measuring the corresponding degradation in the organization's performance.[22] Although such a procedure might produce valid results, there are obvious practical limitations. If the information were truly valuable, withholding it for any length of time may prove to be a very expensive way of determining its value. In addition, unless the information

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[21]Ralph O. Swalm, "Utility Theory—Insights into Risk Taking," Harvard Business Review, November-December 1966, p. 124.

[22]Gregory and Van Horn, Data-Processing, p. 574.

is already being used, one can only approximate what its impact would be.

In spite of its limitations, the theories of "managerial use" do have merit as a vehicle for defining the concept of information utility. First, they recognize the fact that the utility of information must be measured in relation to its impact on the performance of an organization. In this context an organization is defined as a homogeneous grouping of people and facilities working toward a set of common objectives. Thus, the utility of information, or any other commodity, is a measure of the impact of the information upon the attainment of the organization's objectives.[23] Second, these theories recognize that information does not have intrinsic value, instead its value depends upon the effectiveness with which it is used to attain certain objectives. The "user's" capabilities and restrictions cause information to have, or not to have, utility. For example, to a pauper (user) information about a trend in the stock market would have little utility. To a millionaire (user) the same information may be worth several thousand dollars.

The term user will occur frequently in this thesis, therefore a formal definition is in order. An information "user" is a person or agency within an organization that considers a particular item of information in making a decision which will ultimately influence the attainment

[23]John A. Postly, "Behavioral Factors in Information Systems," Information Systems Workshop, Washington, D.C.: Spartan Books, 1962, p. 86.

of the organization's objectives. The exclusion from this definition of functionaries who collect, process, or communicate information is intentional. These functionaries produce information and, in that capacity, they contribute to its cost. Ultimately, it is the decision-maker who determines the amount of value that will be derived from the information.

Gregory and Van Horn acknowledge the shortcomings of each of the three categories of information value theories, but they suggest:

> Nevertheless, it is worth examining the value of information in four of its aspects: quality, quantity, timeliness, and relevance to the Management's ability to take action.[24]

Each of these aspects of information value will be discussed separately.

Quality is defined as the "degree of correspondence between the report about a situation and the actual situation."[25] This definition is the same as that of accuracy which was discussed earlier. Quality adds to the utility of information in "that it reduces the range of uncertainty about what action to take and that it makes management more willing to take prompt and vigorous action."[26] However, there are limits to the amount of quality, or accuracy, that is useful in a particular situation. Increased quality of information, in general, causes additional cost, but there is a point at which additional quality fails to be more useful.

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[24]Gregory and Van Horn, Data-Processing, p. 574.

[25]Ibid.

[26]Ibid., pp. 574-75.

The aspect of quantity is related to the predictability of the environment in which information is to be used.[27] If the situation about which a decision is to be made is very uncertain, then a large quantity of information may be useful. On the other hand, if there is little doubt about the situation or if there is a restriction on the number of options available to the decision-maker, a large quantity of information may be more hindrance than help.

Ackoff champions the cautious approach to the aspect of quantity. He suggests that managers "suffer . . . from an overabundance of irrelevant information."[28] His position is that managers are being suffocated with too much information and that any additional information "cannot be expected to be used effectively."[29] He recommends that more emphasis be placed on the filtration of irrelevant information. This would reduce the amount of time that the decision-maker must allocate to studying information and allow more time to deal with the problem at hand. There is a compromise to be made with respect to quantity. Too little information restricts the user's perspective of the problem. Too much information tends to obscure the pertinent facts. Optimum information utility is achieved somewhere between the two extremes.

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[27] Ibid.

[28] Ackoff, "Management Misinformation Systems," p. B-147.

[29] Ibid., p. B-148.

Timeliness is a general category which includes three separate aspects of information utility. These aspects are defined as:

1. Interval—the length of time between the successive preparation of reports. The interval determines the frequency of reports.

2. Delays—the length of time between cessation of data input and completion of a report. The delay determines the responsiveness of the processing system.

3. Reporting period—the length of time covered by a report. The reporting period may be shorter or longer than the interval.[30]

Variations in the length of any of these timeliness aspects can influence the utility of the information in a report. Utility can be optimized with respect to improvement cost by choosing the most effective length of time for each aspect.

The most effective interval is a function of the variability of "operational results" that occur during the interval. A highly variable process requires a short interval between reports to stabilize control of the process. Conversely, a very stable process allows a longer interval. The latter case would be less expensive to support with information, because fewer reports would be required. Further, if a process were relatively stable, there would be no advantage to having very frequent reports, although

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[30]Gregory and Van Horn, Data-Processing, p. 576.

cost would increase proportionately with increases in frequency. Also, increasing the frequency of reports causes an increase in the quantity of information that a user must attempt to comprehend. This tends to "overburden" the user and inhibit his decision-making ability.

The most effective delay length is determined by a similar relationship. The variability of "operational results" during the delay is the controlling factor. This aspect is of considerable importance in information systems analysis because it is the essence of the perpetual conflict between proponents of "realtime" and "non-realtime" information systems designs.[31] Reductions in the delay aspect of an information system require major modifications in the processing equipment. In sophisticated EDP systems this means faster and more expensive computers or the addition of expensive input-output devices, or both. These additional expenses must be justified in terms of the increased utility that will result from a more responsive system. For example, if the interval of a report were one month, it would appear that the reduction of a delay from one day to one hour would not make a significant improvement in the usefulness of the report, unless the decision environment were very peculiar.

The most effective length of reporting period is determined by a compromise between short reporting periods which accentuate random variability and long reporting periods which tend to distribute the impact of significant events

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[31] Schoderbek, Management Systems, pp. 413-18.

among other data. This determination involves the aspects of quality and quantity. A long reporting period may require a report that is quite large and difficult to comprehend, whereas a short reporting period may result in a report that lacks accurate detail.

One aspect of timeliness that is overlooked by Gregory and Van Horn is reaction time—the length of time between the end of the "delay" and the implementation of a decision based on the information in the report. A decision, by itself, does not affect the attainment of an organization's objectives. It is the implementation of the decision which causes the organization to benefit from the information. If the user fails to implement his decision or takes a long time in implementing it, the timeliness with which the information was prepared is of little consequency. The user's reaction time is a function of his personal responsiveness and of the demands of his decision environment.

Quality, quantity, and timeliness are the primary determinants of information value. They are also the primary determinants of information cost. An increase in any of these factors will increase the cost of the information at a growing rate.[32] On the other hand, an increment of increase in any of these will not always result in a comparable increase in utility. Without regard for the actual functional relationship involved, it is proper that utility be measured in terms of the same parameters that contribute to information

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[32] Gregory and Van Horn, Data-Processing, p. 589.

cost. In this manner an increase in cost can be translated directly into the corresponding increase in utility, or decrease in utility as the case may be.

The final aspect of information value proposed by Gregory and Van Horn is that of "relevance to management's ability to take action." For a user (management) to take action he must have the opportunities and resources necessary to implement a decision. This aspect is of a different order than the first three, although Gregory and Van Horn do not recognize it as such. Instead of contributing directly to the utility of information, the relevance aspect is a limiting factor which restricts the range of values for quality, quantity, and timeliness which are meaningful in a particular decision environment. The interpretation here is that in the case of timeliness, for instance, there are only certain ranges of interval that are relevant to the decisions which must be made. If environmental considerations dictate that a particular decision must be made once a day, then the necessary information should be updated daily. If the decision-maker gets new information only once a week, all of his decisions, except one, will be uninformed guesses. If the information is updated every hour, he can make use of only one report per day and he has no utility for the others. The interval requirements are restricted, in this case, to not less than one day, with decreasing utility associated with intervals of more than a day.

A different appraoch to the question of relevance is offered by Moravec:

> ". . . an individual's capacity for making sound judgments about a complex situation may be seriously impaired by supplying him with a lot of information which he believes would be relevant but whose influence on the situation is not clear to him.[33]

In complex situations too much information may decrease the utility of the information that is available. Ackoff recommends that filtration of irrelevant information, formal decision-rules, and performance feedback can be employed to improve the quality of decisions in these situations, thereby improving the utility of the information.[34] In very complex decision processes the utility of information may be optimized by providing small quantities of highly critical information that have direct influence on the use of formal decision-rules. This approach suggests that the complexity of the decision environment is also a limiting factor which restricts the ranges of the primary aspects of utility.

To evaluate these limitations it is necessary, first, to identify the degree of criticality which pertains to the information that is usable in a decision process. This is the same as identifying the "need" for information, with the additional requirement that the degree of "need" be specified. Schoderbek suggests that this can be accomplished by a probabilistic evaluation of the uncertainty associated with the several alternatives available to the decision-maker.

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[33] Moravec, "Designing Information Systems," p. 130.

[34] Ackoff, "Management Misinformation Systems," p. B-150.

> If the decision-maker is practically certain of which alternative he will decide upon, then this choice would have a probability close to unity while the other choices would approximate a zero probability.[35]

This approach is a step in the right direction, but it has a weakness which can best be demonstrated by a short example. If the probabilities of choosing between two competing alternatives were 0.95 and 0.05, Schoderbek's method would indicate that there would be little use for information about the decision environment. However, if the first alternative would always return $100 while the second had a 0.4 probability of returning $200 and a 0.6 probability of returning $500, the amount of information required to make a sound decision would not be clearly demonstrated by Schoderbek's method. The organization can expect to profit by $280 above its normal return, when the proper conditions exist for choosing the second alternative. Each time the decision is made, it would appear that information concerning the conditions which would allow the second alternative to be chosen, would be worth $14 (0.05 x $280) minus the cost of the information. Although this hypothetical example does not disprove Schoderbek's method, it does suggest that there is room for further study.

Another aspect of information value which serves as a limiting factor is the human element. The human element has established an impressive record in the subversion of information systems progress.

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[35] Schoderbek, <u>Management Systems</u>, p. 44.

> Indeed, the remark, "It would be a great system if it weren't for the people involved." is more than mere witticism or facetiousness. In the man-to-machine but especially in the man-to-man system it is the human element that merits greater attention.[36]

The purpose of measuring information utility is to establish a basis for evaluating changes in an information system. The human element of a system is, by nature, resistant to change and this resistance can negate some, or all, of the benefits that one might expect to obtain from a system improvement.

There are several factors that cause resistance to change. The simple lack of understanding may be the most critical. If some new item of information is provided to a user and he does not, or cannot, comprehend its implications to his decision environment, the information will have little utility, regardless of the effect that a system designer may have anticipated. The "hard-nosed" solution to this problem is to replace the user with someone who does comprehend. But, this solution has limitations. The individual concerned may be extremely valuable to the organization in other respects. The degree to which this type of conflict is resolved has an important influence on the utility which will ultimately be derived from the information.

The desire to maintain status may also contribute to the resistance to change.[37] A manager's primary resource for maintaining his authority is his superior knowledge about the

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[36] *Ibid.*, p. 185.

[37] Lawrence K. Williams, "The Human Side of a Systems Change," *Management Systems*, edited by Peter P. Schoderbek, New York: John Wiley and Sons, Inc., 1967, p. 198.

situation he controls. If he sees his supply of information threatened by a change in the system, he will have a tendency to resist that change. The logic which motivates the change may soften that resistance, but it will not eliminate it. Williams depicts the predicament of such a manager in a hypothetical conversation between an information system designer and an information user:

> I [the user] am terribly afraid I will never be able to understand this new system, and no matter how much you talk or how much information you give me, I will never be on top of the new system the way I was with the old.[38]

Behavioral scientists frequently use the term "threshold" as a means of describing behavioral phenomena. In reference to the human element it may be useful to describe an information user's threshold for change as a point beyond which the user's resistance causes a reduction in the utility of information. In many cases this limit may be high enough that it does not pose a practical problem. But the possibility that it can become a critical factor does exist. As such, it is worthy of consideration in the evaluation of information utility, although the establishment of a user's threshold for change will require a great deal of subjectivity.

The various points of view presented in this section portray the current state of the art of evaluating the utility of information. In each concept there are unique aspects of information value that require consideration in the development of a methodology for evaluating utility. Because of the

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[38] Ibid., p. 196.

general lack of agreement on the importance of each aspect, each was considered of equal importance in developing the basic hypothesis about information utility which summarizes the preceding discussion and which provides the foundation for the research of this thesis.

Hypothesis. The utility of information is a measure of the effectiveness with which information is employed to attain the objectives of a particular organization. The units of utility are defined in the same terms that the organization uses to measure the attainment of its objectives.

Utility has a tangible component which is the function of three primary parameters: the quality, the quantity, and the timeliness of the information in question. In a particular decision environment the range of values that can be considered for these parameters is subject to limitations which are determined by:

a. The degree of uncertainty surrounding the decision variables.

b. The relative value of the alternatives available to the user.

c. The user's ability to extract relevant information from the totality of information available to him.

d. The resources (authority, time, material, money, etc.) available to the user for implementing the decisions that he is expected to make.

e. The user's threshold for change in his information supply.

f. The number of users that deal with a particular type of information.

Utility has an intangible component which cannot be measured in terms of the parameters described above. Rather than assigning some arbitrary value to the intangible component, this evaluation could be made by determining the difference between cost and tangible utility. Then a subjective evaluation could be made as to whether or not the intangible value is worth this difference. An alternate method would be to translate the intangible benefits into superimposed constraints on the performance criteria of the information system, when the intangible utility is considered to be very high.

STATEMENT OF THE PROBLEM

The hypothesis which has been proposed is a synthesis of all the points of view that have been presented. Due to the general lack of agreement among the practitioners on the relative importance of the various parameters, there has been no attempt to infer specific functional relationships between the parameters and the utility of information. In the hypothesis all parameters have been assumed to be of equal importance. The problem, therefore, is to develop a method for evaluating information utility and to identify these functional relationships.

The criteria for judging the validity of the method proposed are that the method must:

a. Measure information utility in the same units that are used to measure information cost (i.e., dollar value) in order to facilitate a direct comparison between utility and cost.

b. Produce a measure of information utility which reflects the degree to which a proposed system change will effect the attainment of organizational objectives.

c. Produce a measure of information utility which can be related to the current level of operation in the environment which the proposed information system is designed to improve.

d. Be sufficiently general to allow application in a variety of environments.

e. Be capable of demonstrating the effect of variations in the three primary parameters of information on the utility to be derived from the information.

PROCEDURE

The procedure employed to develop and test a method for measuring information utility was executed in six phases.

Phase 1. This phase was a general study of the experimental environment to identify organizational objectives and to identify a well-defined information subsystem within the environment which was small enough to allow a detailed analysis by a single researcher, yet complex enough to include the variety of problems associated with a large information system. This dichotomy was resolved by a pragmatic compromise between the competing goals.

Phase 2. This phase was a detailed study of the operational subsystem of the experimental environment which was supported by the information subsystem. The purpose of this phase was to define the operational subsystem in terms of the parameters which affect its level of operation and which, in turn, effect the attainment of the organizational objectives.

Phase 3. This phase was a detailed study of the existing information subsystem to define its parameters and limitations based on the hypothesis proposed in the Introduction to the Problem.

<u>Phase 4</u>. This phase was an analysis of the current and proposed information subsystems in the context of the experimental environment from which a model of the combined subsystems was developed to study the effect of variations in information parameters on the operational subsystem.

<u>Phase 5</u>. This phase was a test of the model to determine how accurately it represented the experimental environment.

<u>Phase 6</u>. During this phase tests were run on the model to determine the influence of variations in the information parameters on the attainment of organizational objectives in the experimental environment.

EXPERIMENTAL ENVIRONMENT

The experimental research for this thesis was conducted at the C. F. Martin Company in Nazareth, Pennsylvania. The company, which has been in business since 1833, produces the famous Martin guitars and ukuleles which are known throughout the world as the standard of excellence in the guitar industry. It employs approximately 200 people, of which 85 percent are involved in direct labor and the remainder are involved in management, sales, and clerical work. The business and clerical functions are automated with a small, but sophisticated, electronic data processing system. On the other hand, the production functions are performed manually by master craftsmen to insure the highest possible quality in the instruments that are produced.

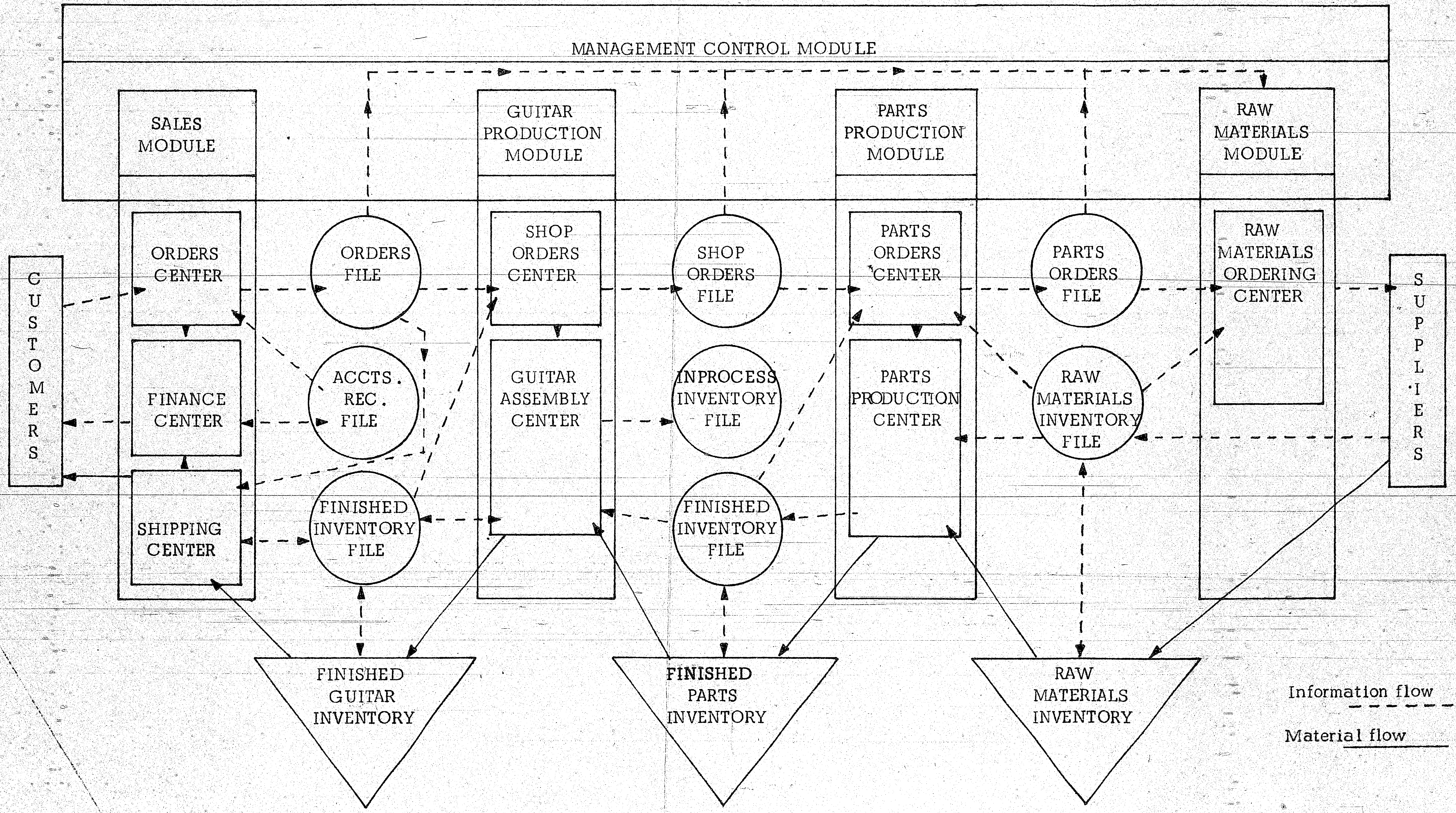
The striking contrast between the complete automation of business functions and the total lack of automation in the production functions reflects the objectives of the company. There is little doubt that the production costs could be significantly reduced by automation in the production system, but not without an equally significant reduction of quality. As a result, automation has not been, and probably will not be, introduced into the production facility. These insights into the management practices of the company confirm its stated objectives with respect to its internal operations.

The primary objective is to maintain the highest possible quality in the instruments that are produced. The secondary objective is to reduce costs, where possible, without degrading the quality of the work.

In addition to identifying the organizational objectives, the purpose of phase one was to identify a limited environment within the organization which would support a meaningful, but manageable, study of the information utility problem. Hence, the information and operational systems of the company were charted to identify the functional structure of the organization. During the conduct of this study it was learned that the company had been contemplating, for some time, the implementation of an automated parts inventory control system. Since this was an actual problem which involved real questions of the economics of a proposed information system change, it was decided to limit the magnitude of the research to the environment which would be affected by the proposed change. The diagram in Figure 1 shows the general functional structure of the company with five internal modules in which there are specialized activity centers. The modules interface on three levels—management control, information flow, and material flow. The experimental environment which was chosen for this research is the parts production module and its interfaces with the remainder of the organizational system.

Phase two was a detailed study of the operational aspects of the experimental environment. The elements included

FIGURE 1.
System Diagram of the Guitar Production and Sales Organization

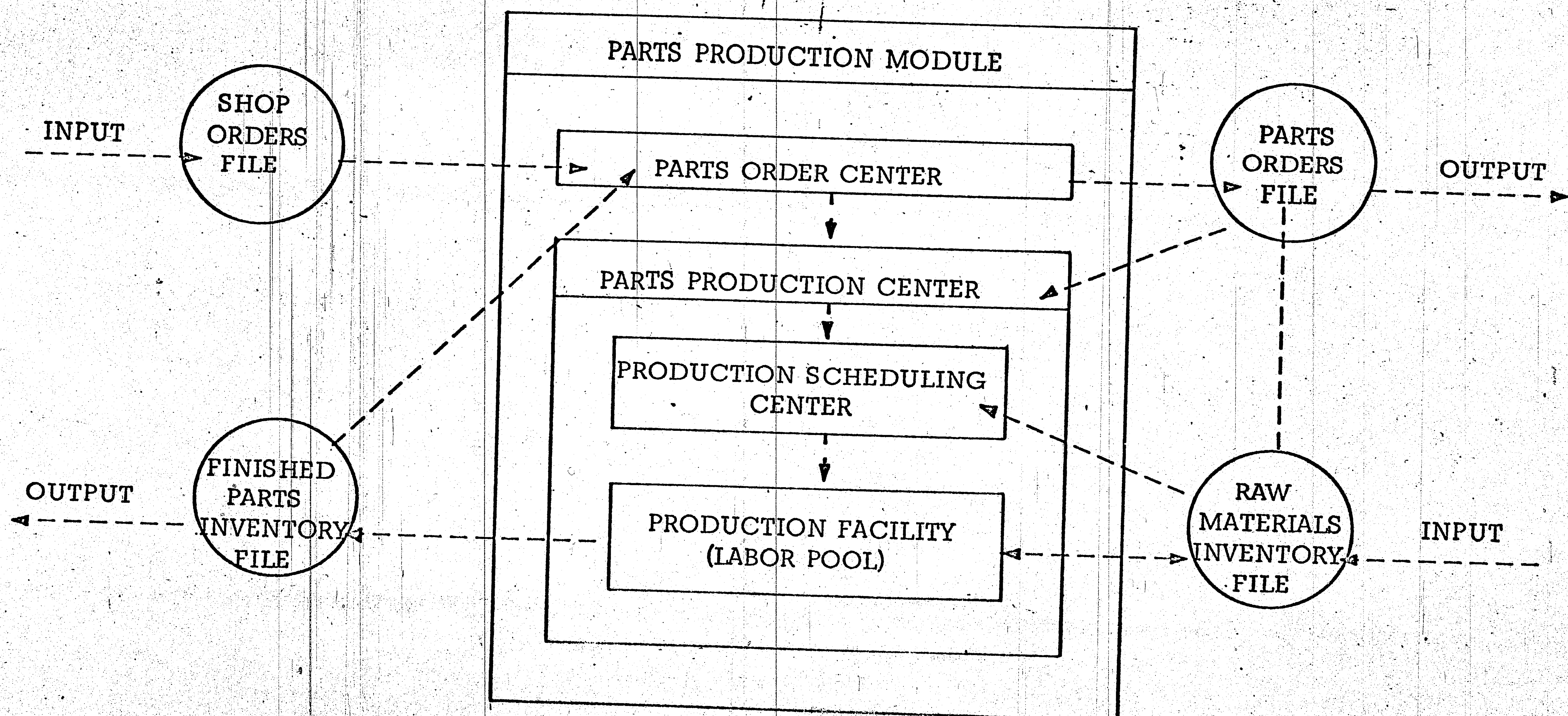


in this environment are illustrated in Figure 2. The parts production module consists of the parts ordering center and the parts production center. The module operates on a stock replenishment principle. As parts are removed from the parts inventory by the guitar assembly center they are replenished by the parts production center. This replenishment of parts, in turn, produces a drain on the raw materials inventory. The raw materials to be considered here are all wood—rosewood, spruce, mahogany, oak, and ebony. These materials arrive at the plant in various configurations that are compatible with the parts for which they are intended. The supply of wood is a critical problem, but the company maintains a sufficient raw materials inventory to prevent shortages during the periods when the supply is disrupted.

From the raw materials the parts production center makes 23 different categories of parts in which there are approximately 150 part types, each with a unique design. The parts are produced in batches by part type. The batch sizes are dependent upon availability of storage space, consumption rate, availability of raw materials, and the availability of production facilities. Batch sizes are not determined by economic order quantity analysis, instead they are determined by the experience and judgment of shop personnel.

The parts production center has one foreman and 19 workmen who are each trained in a variety of jobs. Many of the parts produced in this center require five or more

FIGURE 2
Information Flow Diagram of the Experimental Environment



separate operations. Altogether there are close to 500 operations, each requiring a unique machine setup. Because of the large number of operations and the limited machine facilities, the problem of scheduling jobs is fairly complex. The scheduling of jobs is a matter of intuitive judgment on the part of the foreman. There is no analytical scheduling method employed. The effectiveness of the parts scheduling process is evaluated by the timeliness with which the production center meets the demand for parts in the assembly center. Therefore, with respect to the parts production center, there is an implied objective which is to satisfy the demand for parts in such a manner as to avoid stockouts at the time of demand. The production center operates at about 90 percent of capacity, consequently, there is only a small margin of excess capacity to absorb scheduling errors which cause a failure to meet this objective.

As parts are produced, they are stored in bins from which they are drawn, as required, by the guitar assembly center. The storage area rents for a specified amount of X dollars per square foot per year. The actual value was translated into a value of Y dollars per bin per day from which the storage cost per part per day was calculated based on the number of parts, by type, that can be stored in a bin. Because of the limited storage space available and the need for capital to maintain a large raw materials inventory, the capital investment in the parts inventory is assigned a 25 percent rate of return by the company management. This figure was translated into a carrying cost per part per day for each type of part. These costs and other costs associated with the manufacture of each part are summarized in the bill of materials in Appendix III.

The demand for parts is solely dependent on the parameters of the guitar assembly center. Shop orders for an average of 27 lots of 25 instruments each are issued biweekly. Each lot includes only one model of guitar, but in a given shop order there may be several lots of the same model. In general, all parts are assembled during the first three days of production on a particular lot, except for the neck, fingerboard, and bridge. The neck and fingerboard are required approximately 23 working days after the lot is started and the bridge is required approximately 22 working days later. The current output of the guitar assembly center is rated at an average of 68 guitars per day. The company makes 27 standard models of guitars and ukuleles of which 18 guitar models constitute 99.0 percent of the total number of instruments produced and 99.3 percent of the total parts inventory. Figure 3 illustrates the percent of the total number of instruments produced and the percent of the total dollar value of the inventory consumed, by model. A dummy model was used to represent the additional nine models which constitute only 1.0 percent of the production.

Parts are drawn from the finished parts inventory in sets of 25. If there is a shortage of parts, when a lot is to be started, a different lot will be started in its place

FIGURE 3

Summary of Current Guitar Production by Model

Model Number	Percent of Guitars Produced	Percent of Parts Inventory* Consumed
1	3.8	2.0
2	2.4	1.3
3	3.0	1.7
4	3.8	2.1
5	2.1	1.2
6	1.5	1.5
7	2.4	1.3
8	0.8	0.9
9	19.2	11.9
10	1.9	1.2
11	21.3	30.7
12	1.3	1.9
13	13.8	19.6
14	1.1	1.5
15	1.6	2.3
16	0.6	0.8
17	11.8	7.5
18	6.7	9.7
19**	1.0	0.7

*Based on Dollar Value

**Dummy Model

and a priority parts order will be issued for the parts that are not on hand. Because a large buffer stock of parts is maintained, this situation does not develop very often. Consequently, there is little historical information from which the effect of these "demand-stockouts" can be evaluated.

Phase three was a study of the information subsystem which supports the parts production module. In general, parts orders are generated on the basis of two kinds of information—the number of finished parts on hand and the expected demand for parts. Under the current system the individuals, who draw parts, are responsible for checking whether the reorder points have been reached. There is no standard cycle for conducting parts "counts." Instead the counts are conducted whenever parts are drawn. If the stock of parts is below the reorder point at this time, this fact is reported to the shop foreman who then makes the decisions on wehther or not to order the parts and how many should be ordered. The reorder points are arbitrarily set at some fraction of the capacity of the storage bins based on past experience with the parts order cycle and the anticipated demand for parts. The reorder points are, therefore, sensitive to the projected sales of the models for each respective part. This influence is applied through the shop order center. The availibility of raw materials is also considered in these decisions, but it seldom occurs that the raw materials are not on hand.

When a parts order is received in the parts production center, the center's foreman must schedule the production of the parts, have the necessary raw materials assembled, and assign the men and machines to do the work. If there is a significant shortage of men, machines, or materials the parts order will be backordered and started at a later date. Since some parts are more critical than others, the backorders must be worked off on the basis of the priority of need for each part.

The proposed parts inventory control information subsystem to support this module would provide periodic reports about the number of parts of each type that are stored in the parts inventory. The exact manner in which this would be accomplished is not decided at this point, nor is it pertinent to this research. The company's interest in such a system is to reduce the amount of stock that is normally kept in the inventory. In doing this, however, the proposed information subsystem modification must be compatable with the company's objectives with respect to the parts production module. In order of importance, these objectives are:

a. Maintain the highest possible quality in the parts that are produced.

b. Reduce the cost of and capital investment in finished parts inventory.

c. Eliminate or at least reduce "demand-stockouts" that affect the production of instruments.

The first objective is intangible in that it is difficult to assess the value of quality in measurable terms. However, there is considerable importance placed on quality by the realities of the company's market. Consequently, it is not unrealistic to interpret this objective as a constraint on the proposed information system. The constraint is that the proposed system may, in no way, degrade the quality of the instruments that are produced.

The second objective is essentially a "cost avoidance" objective. The degree to which the proposed system effects the attainment of this objective can be measured directly from an analysis of the inventory costs. In this respect the objective is tangible, although there is an element of uncertainty involved in predicting the savings that will materialize after the proposed system is installed.

As stated earlier, the third objective is intangible, in that there is insufficient historical evidence from which to evaluate the effect of a "demand-stockout." This matter can be handled in either of two ways. First, as a limitation to be imposed on the proposed system whereby stockout avoidance would be insured to some specified degree by the system design. Second, it could be handled by determining the magnitude of the stockout problem for a particular system design and then subjectively evaluating this deficiency in relation to the difference between the cost of the particular system design and the tangible utility to be derived from that design.

The quality of the information generated by the current information subsystem in the experimental environment cannot be formally evaluated, without a very time-consuming data collection effort. Inventory "counts" are performed by workmen making gross estimates of the percentage of a bin that is occupied by parts whenever they have occasion to draw parts from a bin. These estimates are reported verbally and are never recorded. In lieu of a formal evaluation of the accuracy of these estimates, the assumption has been made that they are a normally distributed random variable with a mean value equal to the actual number of parts on hand and having a standard deviation equal to 10 percent of the mean value. This assumption is based on a personal subjective evaluation of the actual estimation methods employed. A more detailed evaluation was not practical.

Gross estimates of the demand for parts are sufficiently accurate for the current mode of operations. With respect to five models, which comprise 72.8 percent of the total number of instruments produced, the average weekly demand for each model was computed for a six-month period. During that period the average demand for any two-week period did not vary more than 15 percent from the six-month average. This consistency of demand allows an experienced foreman to effectively anticipate the demand for parts. The degree of inaccuracy that is characteristic of both the inventory estimates and the demand estimates does not pose a critical problem under the current system, because the relatively large parts inventory compensates for these inaccuracies.

The quantity of information generated by the current information system is a bare minimum. There are only two formal documents in use. A single-page shop order is issued biweekly containing the lot number, the number of instruments to be produced in a lot (normally 25), and the lot's model number. Special orders for non-standard models or for small lots are also included in this document. Parts orders are issued on an "as required" basis and consist of an office memorandum, with a carbon copy, listing a description of the part, the number to be produced, and the date required. One copy is sent to the raw materials purchasing center and the other is sent to the parts production center where it is returned to the shop foreman after the order has been filled. Production priority information is communicated informally.

The timeliness of the information generated by the current information subsystem is characterized as follows. Shop orders are prepared externally to the experimental environment, therefore, the only timeliness aspect of this document that is pertinent to this analysis is the interval between successive inputs to the parts production module. The length of this interval is ten working days, although supplemental shop orders are issued whenever there are less than three lots remaining on the current shop order. This occurs about three times a year.

As stated earlier, the interval between parts "counts" is very irregular and depends upon the frequency with which a workman has occasion to draw a particular part. For parts that have a high demand the frequency may be as often as daily, while for some of the lower demand parts the frequency may be less than once a month. The delays in reporting this information to the shop foreman are insignificant, when the magnitude of the other variables is considered. The physical distance between the men involved allows face-to-face communication. Only when there is a failure to report the shortage of a part, does the delay become significant. The reaction time, which is the time between the report of a shortage and the arrival of the corresponding parts order at the production center, however, does play a significant role in the effectiveness of the parts ordering system. Three different people handle the parts order before production can begin on the particular part. Each person involved has other duties and processes parts orders as his other duties permit. The reaction times normally vary between one and three days, but when there is a critical need for parts, the formal procedure is simply to follow up a verbally processed order. This informal procedure is not limited to critical situations. It is used in about 25 percent of the cases. This verbal coordination reduces the average effective reaction time to about one day.

Since the information generated in this experimental environment is "status or point-in-time" information rather than a summary of past events, the concept of a reporting period is not relevant to the analysis of the timeliness aspect. If the history of changes in the parts supply were being considered, then the length of the reporting period would have to be considered. Such information might be useful in the proposed information system as a tool for predicting the supply of parts, but it is not used in the current system.

Limitations on the managerial use of information are imposed by the practical constraints of the experimental environment. The degree of uncertainty surrounding the decision variables in the current information system is the lower limit of the degree of certainty that would be practical in the improved system. The upper limit is imposed by the characteristics of the operational system. The uncertainties surrounding the decision variables are derived from three sources.

The first source of uncertainty is the number of parts in stock. Except for occasional failures to report a part that is below the reorder point, the foreman can be relatively certain that his parts supply is adequate. The errors that result are absorbed by the large buffer stock that is maintained. However, one of the purposes of the proposed system is to reduce the total amount of parts inventory that is maintained and consequently to reduce the buffer stock levels. When this is done, the acceptable margin for errors in the inventory "counts" will be greatly reduced. The upper limit on the practical degree of certainty required in the proposed system is a function of how low the buffer levels are set.

The second source of uncertainty is the demand for parts. Shop orders arrive biweekly at the guitar production module and at about the same time that all previous lots have been started. Consequently, the type and number of parts that will be required must be anticipated in advance of the shop order. For an experienced foreman, who has extensive knowledge of the history of demand for each instrument model, the need for parts can be anticipated very effectively. ("Very effectively" means that most errors are compensated for by the large buffer stock levels.) Information about the demand for parts will not be improved by the proposed system, because this feature is not anticipated in the design of the system. Therefore, the current degree of uncertainty in the expected demand for parts will remain the same regardless of the parameters of the new system. Consequently, the new buffer levels will be constrained by this uncertainty.

The third source of uncertainty is the parts production cycle itself. Analysis of historical data about the time interval between the issuance of a parts order and the completion of production on the same order indicates that there is little correlation between the time intervals and the number of parts ordered or between the time interval and the type of part ordered. The primary cause of variability in the cycle is the tight scheduling situation in the parts production center. Again the high buffer levels in the parts inventory compensate for the extreme variability in the parts production cycle. The proposed information system will not influence the scheduling situation either. Therefore, the variability in the parts production cycle will continue to require a certain amount of compensation in the buffer stock levels.

The users of the proposed information system are the same agencies that use information in the current system. They are the ordering, scheduling, and production centers. The alternatives available to them are not the either-or type of alternatives. Parts ordering involves continuous ranges of time and amount. Parts orders must be issued far enough in advance to avoid stockouts, but not so early as to compound the parts scheduling problem or to overload the available storage facilities. The number ordered must be consistent with the demand, but not so large as to cause other parts orders to fall behind schedule. The alternatives in scheduling production involve the choice of the next job to be started. The number of alternatives available is the current number of backordered parts orders. In making the choice, consideration must be given to the priority associated with each order and to the availability of production facilities. Evaluation of the relative value of these alternatives will be discussed in the next section.

The users' abilities to extract relevant information from the output of the proposed information system is difficult to quantify, but it will definitely have an effect on the quantity of information that can be used effectively. All individuals involved in the decisions pertaining to the proposed system have numerous other responsibilities. They spend only about one-tenth of their time in dealing with the problems discussed here.

The users have the necessary authority to implement their decisions about the timeliness of orders, number of parts ordered, and jobs to be scheduled, but they are limited in their choice of alternatives by the following constraints:

a. A maximum production capacity which is defined, for practical reasons, as 19 man-days per day.

b. Approximately three months' supply of raw materials on hand at any given time.

c. A limited storage capacity allocated to each type of part.

The constraint of 19 man-days per day is a simplification of a much more complex constraint. The actual capacity of the parts production center is limited by the number of machines available and by the fact that both the men and machines are specialized to perform only certain of the 500 operations that are accomplished in this center. The simplification is made as an approximation of the real system for the purposes of the model to be discussed in the next section.

The human influence on the utility of information from the proposed system is less critical in this particular company than it would be in a more typical industrial environment. The company is relatively small and there is considerable personal interaction among all parties who would be involved in the proposed system. There is, of course, some personal self-interest which may tend to interrupt a planned flow of information, but this self-interest is overshadowed by a more intense commitment to the quality of the instruments that are produced. The three primary users of information in the experimental environment have a combined tenure with the company of eighty years. There is no question that they are qualified in their jobs or that they have the capabilities to use the proposed information system to its fullest extent. The major consideration which must be kept in mind with regard to the proposed system is the impact of the situation that will develop after one of these individuals retires and is replaced by a less experienced man. Because of their experience, the current job holders can accurately anticipate the parts requirements and effectively manipulate schedules and resources without a formal information system to assist them. The adequacy of their intuition is reflected by the profitability of their enterprise. However, it is doubtful that a less experienced replacement for one of these men could, in less than several years, achieve a similar degree of intuitive effectiveness. For this replacement, whoever he may be, the proposed information system will be a valuable "crutch" while he is learning the job. This aspect of the utility of the information is an intangible. If the ultimate design of the system is justified entirely by the tangible utility, then this aspect need not be evaluated. On the other hand, this intangible utility may justify the difference between the cost of a particular system design and the tangible utility that would be derived from it.

DESCRIPTION OF THE MODEL

It would have been possible to study several organizational environments which differed only to the extent that they were supported by information systems with unique compositions of the primary information parameters. The functional relationships between utility and the parameters—quality, quantity, and timeliness—could have been deduced from such a study. However, it is unlikely that such a set of environments could have been found. And, if it had been found, the data collection effort required to support the study would have been so extravagant that the results would not have justified the cost. This type of approach would have resulted in an implicit contradiction of the basic premise of this thesis. An alternative to this approach was to simulate a single organizational environment and its supporting information system in such a manner that the parameters of the information system could be varied to represent alternate information system designs. The latter approach was chosen because it is more applicable to experimental work, yet it produces results that are equally meaningful.

The simulation model developed to study the information utility problem was designed to fulfill the following general requirements:

1. The model should represent the dynamic aspects of the operational system in terms of the functional relationships that were found in phase one.

2. It should represent a supporting information system which reflects the basic concepts of the company's proposed information system.

3. The supporting information system should be flexible enough to allow its design parameters to be varied over the meaningful range of values.

4. The model should reflect the company's objectives either in the form of internal constraints on the operational system or in the form of statistical results which reflect the degree to which a particular system design affects the attainment of those objectives.

The design of the model is also based on certain assumptions which recognize the differences between the model and the realities of the environment which it represents. The first assumption is that the basic operational system of the company will remain unchanged throughout the implementation of the proposed information system. This may, in fact, not be true, but there is no reasonable basis for prediction of changes that might take place. Any major change that might be made would certainly be expected to alter the anticipated utility of the information system. The second assumption is that the demand for instruments will continue to exceed the company's capacity to produce. This assumption is supported by the fact that the finished instrument inventory is normally less than the equivalent of two days' production. In general, instruments are sold before they have been completed, and there is approximately three months' backlog of unfilled orders at any given time. There is sufficient reason to expect that this favorable market condition will continue. The third assumption is that the proposed information system improvement will not influence operations in any area of the organization, except the parts production module. The forth assumption is that there will always be sufficient raw materials on hand to meet the demand. The company seeks to maintain this position and is usually successful. The final assumption is that the company is currently using, and will continue to use, a minimum-cost batch order policy with respect to parts orders. At present this policy is not followed, but it will be instituted along with the proposed information system. Since savings would be derived purely on the basis of converting to this policy and independent of any modification to the information system, the parts order procedure has been designed in the model as though this policy had already been implemented in order to avoid confounding the effect of the policy change with the effect of the information system change.

The simulation model was formulated in the GASP II simulation language which is a Fortran-based language for discrete-event simulations.[39] In this language events are generated as the simulation progresses. Each time that all transactions are completed for a particular event, the next event in chronological order is withdrawn from the event file, the simulation clock is advanced to the scheduled time of this next event, and the programmed transactions are accomplished. Upon completion of the transactions, the process is repeated. This procedure is continued until the clock achieves some predetermined time or until an end of simulation event occurs, at which time the results of the simulation are printed. GASP II consists of several general subroutines which handle the bookkeeping, data collection, and parameter generation functions, but the programmer supplies his own subroutines which describe the particular environment to be simulated. The subroutine listings and flow charts for this particular model are included in Appendix II.

Input to the simulation program consists of four groups of data. Group A is a set of six parameters which describe the particular configuration of the model which is to be tested. Group B is a set of twenty parameters which describe the demand for instruments by model. Group C is a bill of materials which includes production, inventory, and cost parameters for each part by type. Group D is the complete set of regular GASP II data input cards which include, among other data, two initial events which start the simulation and generate all subsequent events. The first event

[39]A. Alan B. Pritsker and Philip J. Kiviat, Simulation with GASP II, Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1969.

(type-1) produces a count of the stock on hand at the beginning of the simulation and the second event (type-6) begins the first day of production. A detailed description of all data required for the model is presented in Appendix III.

After all input data are registered and the various files have been initialized, subroutine GASP finds the first of the two initial events which produces a call for subroutine COUNT. COUNT simulates the data collecting and processing elements of the supporting information system. First, it schedules the next type-1 event at XINTER time units in the future. XINTER is an input parameter which sets the interval between successive reports on the status of the inventory. (A unit of time in this model is considered to be one day.) Next, COUNT makes an estimate of the number of parts that are on hand for each type of part. The estimates are normally distributed random variables with a mean equal to the actual number of parts on hand and a standard deviation of 100 x SIG percent of the current mean. SIG is an input parameter which establishes the accuracy of the information system. If this estimate (EST) is greater than the required buffer stock, no action is taken. If it is less than the required buffer stock, a parts order is generated for one batch (minimum-cost batch size) of that particular part. This order is prepared in the form of a type-2 event and is scheduled to arrive at the production scheduling center at DELAY + REACT time units un the future. DELAY is an input parameter which establishes the delay aspect of the supporting information system. REACT is a computed value which represents the amount of time required to prepare and process a parts order and to issue it to the production scheduling center—reaction time. If a part is ordered by COUNT, the production status of the particular part is assigned a value which indicates that part is on order. This feature prevents any additional orders for the same part until the current order is filled.

A special feature is provided in subroutine COUNT to vary the amount, or quantity, of information that is produced by the supporting information system. Parts are listed in the bill of materials according to the average daily consumption (dollar value) of each part type. The part with the largest daily consumption is listed first, followed by the next largest, and so forth. The number of different part types to be checked by subroutine COUNT is preset as the parameter NQUANT which determines how much information will be reported by the supporting information system. COUNT will check the parts in their bill of materials order, starting with the most critical part. For example, there are 73 part types considered in the model. If NQUANT is set at 50, then only the 50 most critical parts will be counted by the formal system. The remainder of the parts will be checked whenever a workman has occasion to check a particular bin in the process of drawing parts. If he finds that the stock is below the reorder point, based on his estimate of the number of parts in the bin, he will report this fact and an order will be generated. This informal procedure is consistant with the actual procedure which is currently used in the guitar production module and it is simulated in subroutine GUITAR.

Subroutines SETUP, MAKE, and FINISH simulate the activities of the parts production center. Subroutine SETUP is called by a type-2 event. It assigns the men to do the work on a particular parts order, computes the length of each segment of the production cycle, and schedules the event (type-3) which causes the parts to be added to the inventory. Subroutine MAKE is called by a type-3 event at the end of the second segment of the production cycle. The first segment represents the setup time required to prepare the machines and collect the necessary resources for the parts order and the second segment represents one-half of the required production time. At the end of the second segment, all parts are added to the finished parts inventory. In the actual environment the addition of parts to the inventory is a continuous process. Parts are added as soon as they are finished. This process is represented as a one-time addition in order to improve the efficiency of the model. Subroutine MAKE changes the production status of the particular part to allow new orders to be issued and then schedules a type-4 event which produces a call for subroutine FINISH. FINISH signifies the end of production for a particular batch of parts by returning the men to the labor pool where they become available to do another job. If there are insufficient men in the labor pool (XMEN) when SETUP is called for a particular order, the order will be placed in the backorder file until enough men are free to do the work.

The external influences on the parts production module are simulated by subroutines ORDER and GUITAR. These subroutines represent the operations of the shop order center and the guitar assembly center. The raw materials module is not represented in the model due to the assumption that raw materials will always be available.

Subroutine ORDER is called by a type-5 event. It schedules the next shop order by generating the next type-5 event for ten working days in the future. After this event has been filed, subroutine ORDER creates a shop order by randomly sampling the instrument demand distribution (IPROB) to determine which model will be produced in each lot. Sufficient lots are ordered to increase the number of reserve lots to thirty.

Subroutine GUITAR is the parts consumer. At the end of each simulated day, GUITAR is called by a type-6 event. The first transaction in subroutine GUITAR is to schedule the next type-6 event, or the next day, one time unit in the future. Next, the lowest numbered shop order is removed from the file and the stock on hand is checked to ascertain the availability of parts. If all parts are available, they are withdrawn from the inventory at one time. In the actual assembly of instruments, parts would be withdrawn over an extended period of time, but in the simulation this process is compressed into a single point in time to improve the efficiency of the model with no loss of reality. To simulate this process accurately would require a much more complex program with an extravagantly large filing array. As parts are withdrawn from the inventory, the workman, who draws the parts, estimates the number of parts in the bin. If he determines that the reorder point has been reached, he will initiate the parts order process. If the part is already on order—the same deficiency may have been detected by the supporting information system—his new order will not be processed. After the parts for a particular lot have been withdrawn the program's dealings with that lot are completed. In reality, this would be only the beginning of a three-month long assembly process, but during this process there would be no further demands on the parts production module originating from that particular lot. If a full set of parts is not available for a particular lot, the parts will not be drawn and the lot will be returned to the shop order file until the next day. Each day enough lots are started to maintain an average of 68 instruments per day. If there is an insufficient number of lots started in a given day, the shortage will be corrected on the following day. This feature is compatible with the actual operation of the guitar assembly center.

An additional feature is included in subroutine GUITAR which causes the buffer levels—reorder points—to be adjusted whenever a demand for parts cannot be satisfied from the finished parts inventory. When this condition occurs, the buffer level for a particular part is increased by the amount which is short. In this manner, the buffer levels are forced upward to a point where stockouts will be averted. This makes the model sensitive to the organizational objective of eliminating stockouts. Prior to collecting statistics in a simulation run, the program runs for fifty simulated days in order to adjust the buffer levels. Consequently, when statistical collection actually begins, the buffer levels have already been adjusted to the levels required by the particular design of the supporting information system which is being evaluated. The effect of the no-stockout policy is, therefore, reflected in the overall performance of the model.

The performance of the model is evaluated on the basis of two criteria. The primary criterion is based on the parameter STORE. The value contained in STORE at any time during the simulation is the current daily carrying cost of the entire finished parts inventory. Each time that parts are added to or drawn from the inventory the value of STORE is changed in accordance with the interest and storage costs associated with each part. These costs are contained in the bill of materials. Prior to making changes in the value of STORE, the statistical subroutine TMST is called to collect the current value of STORE and the amount of time that it has remained unchanged. In the results of a simulation the mean, standard deviation, maximum value, and minimum value of STORE are printed. The mean value is a measure of the utility which could be derived from a given information system design. The "benefits" of an information system improvement are, therefore, reflected in the difference between the carrying costs of the finished parts inventory under the present information system and the carrying costs under some improved system design which is represented in the model. It should be noted that the impact of the no-stockout policy will be reflected in this measure of performance.

The secondary criterion is based on the parameter TOTINV. The value contained in TOTINV at any particular time during the simulation is the current total dollar value of the finished parts inventory. TOTINV is treated in the same manner as STORE. The mean value of TOTINV is printed in the simulation result and is used to evaluate the degree of conformity between the model and the actual environment which is being simulated. This evaluation is discussed in the next section. TOTINV is not used in evaluating the performance of supporting information system designs.

The decision processes that are represented in the model are illustrated in Figures 4 and 5. This decision matrix depicts the logical processes which are employed in the model but translates them into their respective counterparts in the actual environment. The flow of transactions is counter-clockwise and references to information in the files are made in a clockwise direction. The matrix represents a continuous process which can be entered at any point.

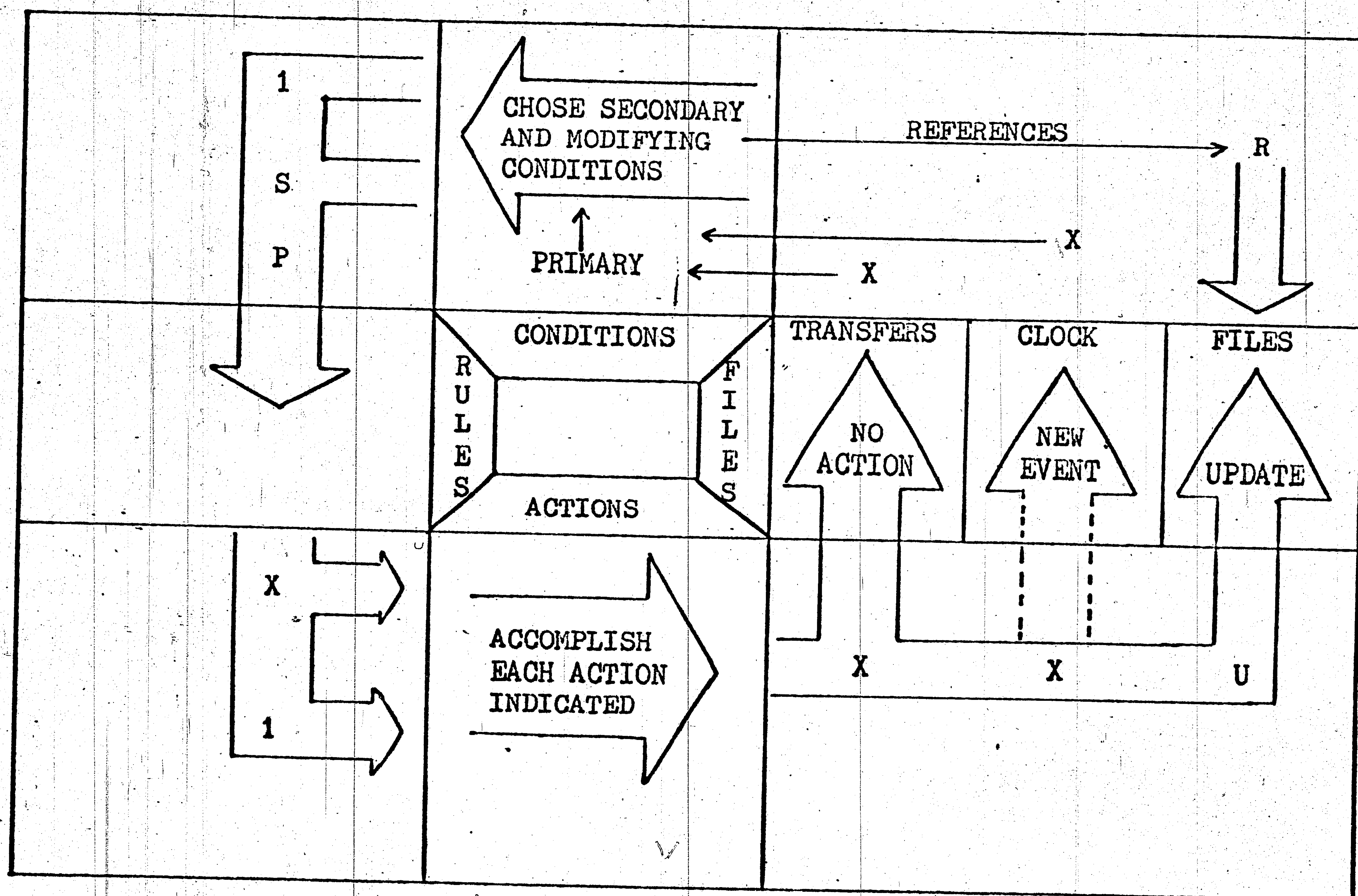
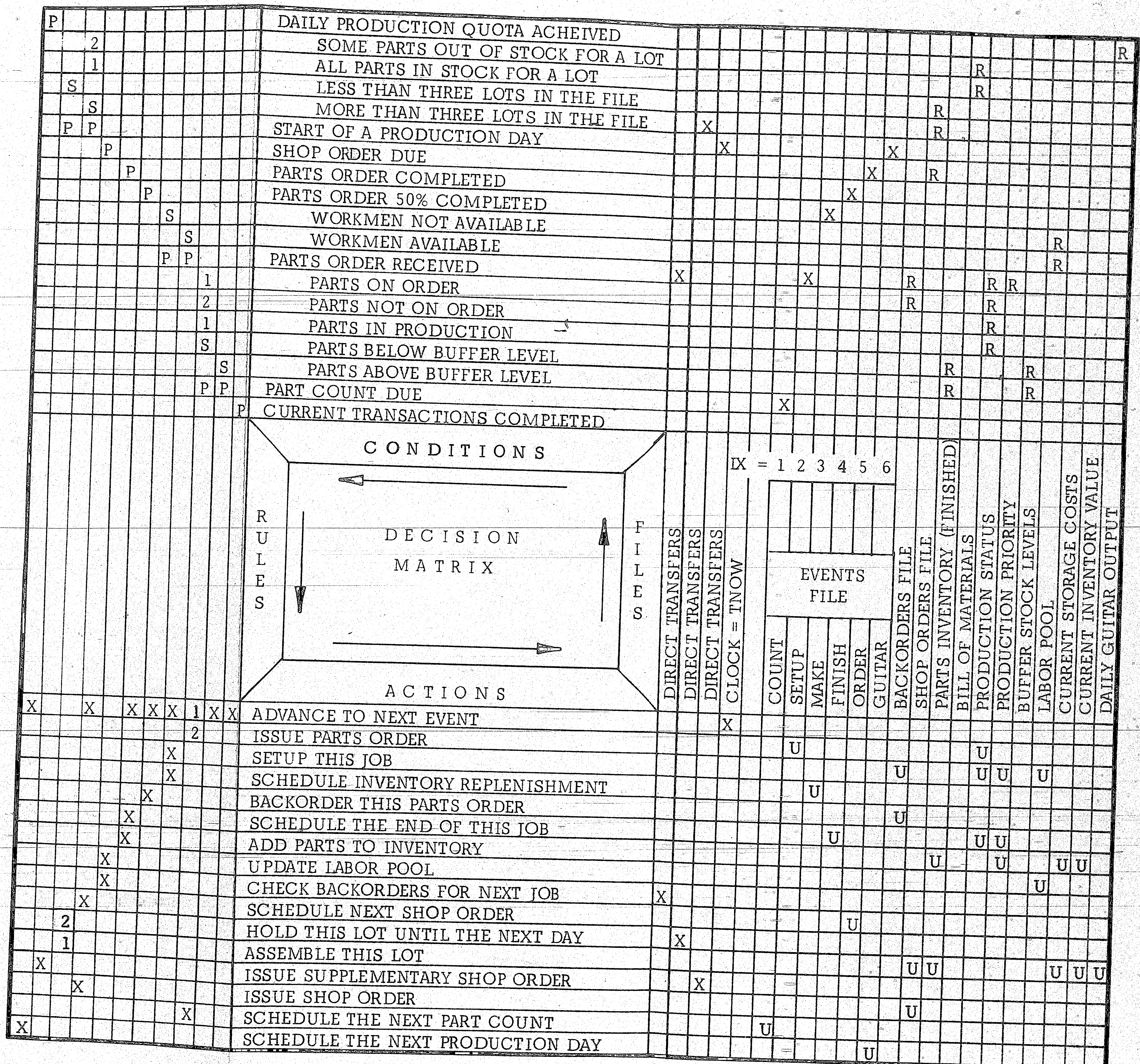


FIGURE 4. General Transaction Flow of Decision Matrix

Figure 5

Decision Matrix
of the
Simulation Program



For any set of conditions which might exist there is a primary condition (P), a secondary condition (S), and modifying conditions (1 and/or 2) indicated in a vertical column to the left of the condition column. Information contained in the file, indicated by a reference symbol (R) to the right of the conditions, determines the set of secondary and modifying conditions which exist. For each set of conditions there is a corresponding set of actions which is indicated to the left of the action column. Actions indicated by an (X) are taken whenever the vertical column is activated by a set of conditions. Actions indicated by a (1) or (2) are taken only when the modifying condition with corresponding number exists. The transactions which describe a particular action are indicated by an (X) or a (U) in the horizontal row to the right of the action column. A (U) indicates that the file above it is to be updated on the basis of the action taken. An (X) indicates that there is a direct transfer to a new primary condition. If the (X) transfers to the clock, all necessary transactions have been completed and the next chronological event is checked to determine the type of event (IX) that is to occur. The vertical column above the appropriate value of (IX) indicates the next set of conditions that will exist, and the process is then repeated. Figure 4 illustrates the general transaction flow.

VALIDATION OF THE MODEL

The validation of the model was conducted by simulating one year of production (250 working days) using the model configuration which represented the actual experimental environment without the proposed information system in operation. This configuration was achieved by removing the initial type-1 event generating entry from the input data. Without this entry subroutine COUNT, which stimulates the operations of the proposed information system, cannot be called to count the inventory on hand. Consequently, the functions which are required for ordering and scheduling the production of parts are performed entirely by subroutine GUITAR. In this subroutine the inventory levels are checked only when a workman has occasion to draw parts from a bin. With this configuration the values which are assigned to the four information system parameters are irrelevant, because they will not be used.

The intention of the validation test was to compare the mean total inventory value, TOTINV, with the company's accounting records of the actual inventory value. However, the company does not maintain records of this type and the information which would be needed is indiscernible from the records which are kept. Therefore, the next best alternative was to have company management personnel subjectively evaluate the degree of conformity between the simulation results and their personal impressions of the mean total value of the parts inventory for the parts which are considered in the model.

During the simulated year, the mean total inventory value was $24,778.53 for all of the parts that were considered in the model. This figure is based on an average simulated production rate of 68.0 instruments per day. The managers were asked to base their evaluations on the past year of production during which time the actual production rate was 62.5 instruments per day. None of the managers questioned was able to render a numerical estimate of the inventory value, but there was general agreement that the simulation result was a reasonable approximation of the average finished parts inventory value during the prescribed time.

If an actual management decision were to be made concerning the installation of the proposed information system, a precise measurement of the actual inventory would have to be performed. Using such a measurement, the stimulation results could then be scaled to insure compatibility between the model and the reality which it represents. However, for the purposes of this research a reasonable approximation of the experimental environment is sufficient.

The second purpose of the validation test was to obtain a measure of the mean value of the inventory carrying costs associated with the existing production system—that is, without the proposed information system. This value can then be used as a basis for determining the amount of improvement that results from the inclusion of the proposed information system. Because of practical limitations on the amount of computer time that could be used in this research it was not possible to run the simulation tests long enough to reach a steady state condition. Consequently, all of the tests that were conducted involved the simulation of only 150 production days, except for the validation test which did not consume as much computing time. In order to produce a measure of the actual inventory carrying costs that would correspond to the other test results, the validation simulation was temporarily halted after 150 simulated days and the intermediate results were printed. At this point the mean inventory carrying cost was $28.47 per day. Although company management personnel estimated that this figure was about fifty percent higher than the actual carrying cost of the inventory, it is based on the same initial conditions and the same simulated time period as the other tests that were conducted with the information system in operation. Therefore, it has been used as the basis for all comparisons with the other test results.

TESTING PROCEDURE AND RESULTS

The method employed to evaluate changes in the design parameters of the proposed information system was a 4 by 3 factorial experiment using the simulation program to predict the utility which would be derived from a particular information system configuration. The independent variables of the experiment were the four information system design parameters—SIG, DELAY, XINTER, and NQUANT. Each variable was assigned three levels which encompassed the meaningful range of values for each variable. (See Figure 6.) All 81 possible combinations of the variables and their levels were tested. The dependent variable of the experiment was the mean value of the parameter STORE during the period covered by the simulation.

Each of the tests was started with the same inventory of parts on hand and the same instrument demand distribution. The initial value of STORE was set at the corresponding inventory carrying cost for the initial inventory. All other program variables, including the random number generator seed, were held constant for all tests. Prior to the initiation of data collection, the program was allowed to run for 50 simulated days in order to adjust the initial inventory to levels that were consistent with the information system configuration that was being tested. Following this start-up

FIGURE 6

Parameter Values of the Factorial Experiment

Variables	Levels (1)	(2)	(3)
(I) SIG	1.0%	5.0%	10.0%
(J) DELAY	0.5 days	1.0 days	2.0 days
(K) XINTER	1.0 days	5.0 days	10.0 days
(L) NQUANT	20 parts	40 parts	60 parts

period the program was run for 150 simulated days during which statistics were maintained on the value of STORE. Figure 7 lists the mean values of STORE for each test and the respective levels of each independent variable.

The analysis of these data was accomplished with the bio-medical statistical program BMDO2V. The analysis of variance table and the marginal means of the mean value of STORE are shown in Figures 8 and 9, respectively.

The results of these tests indicate that the most important parameter of the proposed information system is the interval between successive reports—XINTER. However, the effect of reductions in the interval is the opposite of what might have been expected. Instead of reducing the carrying cost of the inventory, reductions in the reporting interval caused the inventory carrying cost to increase. When the information system was reporting every 10 days, the mean carrying cost (marginal value) was \$22.87 per day which indicates that the company has a utility of \$28.47 - \$22.87 = \$3.60 per day for reports that are updated biweekly. When the information system was reporting every day, the mean carrying cost was \$33.28 per day which indicates a utility of -\$4.81 per day. This result is statistically significant at the 0.99 confidence level.

The degradation of the inventory carrying cost that results from providing too frequent updating of inventory information is not inconsistent with the company's previous experience in this matter. An earlier attempt to reduce the

FIGURE 7

Simulation Test Results

Test Number	Level of Variables I	J	K	L	Mean Simulated Inventory Carrying Cost
1	1	1	1	1	32.30
2	1	1	1	2	30.79
3	1	1	1	3	34.88
4	1	1	2	1	23.11
5	1	1	2	2	29.95
6	1	1	2	3	30.11
7	1	1	3	1	22.37
8	1	1	3	2	22.84
9	1	1	3	3	23.37
10	1	2	1	1	29.25
11	1	2	1	2	28.29
12	1	2	1	3	34.54
13	1	2	2	1	23.48
14	1	2	2	2	29.04
15	1	2	2	3	24.35
16	1	2	3	1	21.91
17	1	2	3	2	22.28
18	1	2	3	3	21.89
19	1	3	1	1	33.98
20	1	3	1	2	30.59
21	1	3	1	3	39.03
22	1	3	2	1	22.41
23	1	3	2	2	24.17
24	1	3	2	3	23.32
25	1	3	3	1	21.83
26	1	3	3	2	23.35
27	1	3	3	3	22.33
28	2	1	1	1	29.95
29	2	1	1	2	29.86
30	2	1	1	3	35.24
31	2	1	2	1	23.03
32	2	1	2	2	23.14
33	2	1	2	3	24.57
34	2	1	3	1	21.69
35	2	1	3	2	24.11
36	2	1	3	3	24.96
37	2	2	1	1	33.81
38	2	2	1	2	33.18

Number	I	J	K	L	Carrying Cost
39	2	2	1	3	32.43
40	2	2	2	1	23.37
41	2	2	2	2	24.59
42	2	2	2	3	24.90
43	2	2	3	1	22.43
44	2	2	3	2	22.74
45	2	2	3	3	23.79
46	2	3	1	1	33.71
47	2	3	1	2	33.90
48	2	3	1	3	36.07
49	2	3	2	1	22.78
50	2	3	2	2	23.55
51	2	3	2	3	24.55
52	2	3	3	1	21.96
53	2	3	3	2	22.43
54	2	3	3	3	23.49
55	3	1	1	1	30.75
56	3	1	1	2	34.70
57	3	1	1	3	34.63
58	3	1	2	1	23.43
59	3	1	2	2	23.66
60	3	1	2	3	24.14
61	3	1	3	1	22.80
62	3	1	3	2	23.21
63	3	1	3	3	23.64
64	3	2	1	1	31.21
65	3	2	1	2	35.10
66	3	2	1	3	35.39
67	3	2	2	1	22.64
68	3	2	2	2	24.68
69	3	2	2	3	23.77
70	3	2	3	1	22.73
71	3	2	3	2	22.81
72	3	2	3	3	23.47
73	3	3	1	1	30.42
74	3	3	1	2	35.11
75	3	3	1	3	39.45
76	3	3	2	1	23.73
77	3	3	2	2	24.59
78	3	3	2	3	24.01
79	3	3	3	1	22.43
80	3	3	3	2	23.44
81	3	3	3	3	23.42

FIGURE 8

Analysis of Variance Table

Grand Mean = 26.85

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
1	2	1.56	0.78	0.49
2	2	2.90	1.45	0.87
3	2	1702.91	851.45	532.50**
4	2	71.76	35.88	22.42**
12	4	13.43	3.35	2.09
13	4	28.14	7.03	4.40*
14	4	5.08	1.27	0.79
23	4	34.00	8.50	5.30**
24	4	7.15	1.78	1.11
34	4	41.69	10.42	6.55**
123	8	21.49	2.68	1.68
124	8	7.79	0.97	0.61
134	8	52.82	6.60	4.13**
234	8	10.19	1.27	0.79
Residual	16	25.66	1.60	
Total	80	2026.64		

*Significant at 0.95 Confidence Level.

**Significant at 0.99 Confidence Level.

FIGURE 9

List of Marginal Means

Variables	Levels	Means
1	1	26.88
	2	26.67
	3	27.01
2	1	26.93
	2	26.59
	3	27.03
3	1	33.28
	2	24.41
	3	22.87
4	1	25.68
	2	26.89
	3	27.99

amount of inventory on hand by providing advance information on shop orders produced a similar result. Because of this advance information, shop personnel began making parts much earlier than was necessary. Consequently, the parts remained in the inventory for an excessive amount of time which caused the total inventory on hand to increase. This problem was avoided satisfactorily by issuing shop orders at the latest possible time.

The second most important parameter of the proposed information system is the number of part types that are checked by the system—NQUANT. The table of marginal means indicates that the least expensive inventory is achieved when only the 20 most costly parts were checked by the proposed information system and the remainder were checked in the usual manner. The company's utility for this type of information is $2.78 per day. When 60 part types were checked, the company's utility is only $.48 per day. Again the effect is the reverse of what might be expected. Checking and reporting on 60 parts, instead of 20 parts, is what many practitioners would refer to as "an improvement in information," however, the effect of this "improvement" does not justify the term. Rather than improving the company's ability to attain its objectives, this change in the information system would tend to frustrate the company's efforts. Although a thorough analysis would be required to interpret the cause of this effect, it would appear that the desire of shop personnel to produce parts as early as possible is also affecting the quantity aspect of the proposed information system. The effect of the parameter NQUANT is significant at the 0.99 confidence level.

The accuracy of the information or the delay in reporting it did not have a statistically significant effect on the performance of the proposed information system. The F-ratio for both of these sources of variation was less than 1.0. However, this statistical result does have significant implications in the evaluation of the utility of the information. The statistical results indicate that there is little or nothing to be gained by designing a highly accurate or very responsive system. If the proposed system's reports of the number of parts on hand are accurate to the extent that the 2-sigma confidence interval is less than or equal to 20 percent of the actual number of parts on hand, there is nothing to be gained by having more accurate information. If the reports are prepared within two days after the inventory is checked, this will be adequate for the ordering of parts. The justification for a system which produces more accurate or responsive information would have to be made on the basis of some other criteria.

No attempt will be made here to explain the interactions among the various parameters. One second-order interaction and two third-order interactions are statistically significant at the 0.99 confidence level. Any interpretation of these interactions would be subject to considerable conjecture unless the interpretations were accompanied by a detailed analysis of the experimental environment. For the purposes of this study it is sufficient to recognize that these interactions do, in fact, exist. The implication of the interactions in the question of measuring the utility of information is that a change in one of the design parameters of an information system can have a significant influence on the "benefits" that one might expect to obtain from altering some other parameter. For example, there is a statistically significant interaction between the length of the delay and the length of the interval between reports. If the interval between successive reports, in this particular environment, were reduced with the intention of obtaining more useful information, a failure to recognize the effect of the interaction could result in the frustration of the efforts to achieve greater information utility. This observation is based on the assumption that the interaction causes a degradation of the effect of a shortened interval. The effect, however, of the interaction may be that it brings about an even greater improvement in utility than would be expected from a reduction in the interval, if the converse assumption were valid. The influence of the interactions must be understood in the context of the particular environment which is being investigated. It is doubtful that the interactions which are characteristic of this particular experimental environment would be applicable, in general, to other environments.

CONCLUSIONS

The purpose of this research was to investigate the functional relationships between the parameters of an information system and the utility of the information that the system produces. The experimental environment which was chosen for this purpose was a small industrial organization which had well-defined lines of communication and control. To this extent the company is not typical of most modern industrial organizations. However, the fact that its organizational structure is well defined makes it an excellent environment for conducting basic research in information systems problems. The fact that the organization is unique, in that many of its manufacturing and business aspects are predicated on the company's overriding concern for quality, prohibits the generalization of the simulation results to other industrial environments. But, it does not limit the applicability of the simulation approach. The only limit to this approach is the degree of difficulty involved in identifying an organization's structure and objectives. The validity and usefulness of the simulation results depend on the analysts' abilities to adequately represent those factors in the simulation model.

The main conclusion that can be drawn from this research is that there is no valid basis for the apriori assumption that an improvement in any one of the information system parameters will automatically produce more useful information. Instead, the evidence from this research indicates that, for any particular environment, there exists a complex set of functional relationships among the design parameters of an information system and the utility of the information that the system produces. Furthermore, it is reasonable to assume that these functions are unique characteristics of any particular environment. It is doubtful that the functional relationships that have been found for C. F. Martin, Inc., would be applicable to any other industrial organization. Therefore, the most profitable direction to follow in the development of a methodology for evaluating the utility of information would appear to be toward the goal of establishing a general simulation program which could be adapted to a variety of industrial environments. This approach has greater promise than an attempt to develop some analytical procedure to be used for approximating the functional relationships. As with simulation techniques in general, one of the most important benefits of this approach is the experience and insight gained by developing the simulation. The importance of this aspect should not be underrated in evaluating the approach to be taken.

Several conclusions can be drawn from this research with respect to the company's interests in their proposed information system. First, assuming that the company managers were correct in their evaluation of the validation test results, the maximum utility which can be derived from the proposed system is $3.60 per day or $900 per year unless the basic concepts of the system are altered to include such features as production scheduling analysis, parts demand analysis, and stricter management control of parts ordering. Second, the company has little or no additional utility for information that is more accurate than that which is currently provided. Similarly, the company has little utility for immediate inventory information. If the parts ordering center receives inventory information within two days of a report's cut-off time, this can be used as effectively as if it had been received within ten minutes. Third, the information provided by the proposed information system need not deal with more than the 20 or 30 most costly parts. Any additional information cannot be used effectively. Finally, there is a negative influence created by updating the information too frequently. Monthly updating appears to be the optimum condition with respect to the utility of the information.

RECOMMENDATIONS FOR FURTHER STUDY

The review of the literature indicated that there was considerable need for study on the problem of evaluating the utility of information. The work that was done in the preparation of this thesis was a first step in the development of a methodology, but there is much more to be done before information systems improvements can be evaluated on a non-subjective basis. As a result of this research there are two recommendations for future study in this field.

1. The approach that was employed in this thesis should be duplicated in other industrial environments in order to verify or disprove the results and conclusions that have been offered on the basis of this research. In the process of doing this more information will be acquired on the nature of the functional relationships that exist in the evaluation of information utility.

2. Additional effort should be applied to the problem of identifying the general characteristics of the relationships among the information system design parameters and the utility that can be derived from information. These efforts should be directed toward the development of analytical functions which can be used to extrapolate the results of simulation models and provide a more general basis for analysis.

APPENDIX I

DEFINITION OF PROGRAM VARIABLES

This appendix defines the variables that are used in the simulation program. The first section deals with the GASP II variable ATRIB(I). The second section defines all other variables.

Section 1

The variable ATRIB(I) is the Ith attribute of an entity or event that has been or will be stored in the array NSET(J, I). This array contains all of the files that are generated by the program. The specific definition of ATRIB(I) depends upon the particular file in which the entity or event is stored.

<u>Event File (file-1)</u>

ATRIB(1)	The scheduled time that the associated event will occur.
ATRIB(2)	A number which defines the event-type. This variable is converted to the integer IX by subroutine GASP and is used in subroutine EVNTS (IX, NSET) to call the appropriate transaction subroutine.

ATRIB(3)* The part number of a particular parts order.

ATRIB(4)* The number of parts that are to be made for a particular parts order.

ATRIB(5) Not used.

ATRIB(6)* The time when the work on a particular part will be completed.

ATRIB(7) Not used.

Backorder File (file-2)

ATRIB(1) Same as file-1.

ATRIB(2) Same as file-1.

ATRIB(3) Same as file-1.

ATRIB(4) Same as file-1.

ATRIB(5) The time that the order arrived at the production scheduling center times the production priority of the particular part. The backorders are arranged in file-2 according to the value stored in ATRIB(5)—lowest value first. If the production priority changes while the order is in the backorder file, the file will be rearranged accordingly. A random decimal number is added here to differentiate orders that arrived at the same time with the same priority.

ATRIB(6) Same as file-1.

ATRIB(7) The production priority for a particular part.

Shop Order File (file-3)

ATRIB(1) The lot number of a particular lot. The lots are arranged in file-3 according to the lot number—lowest value first. Lot numbers are assigned in numerical order beginning with number one.

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*This attribute is used only with respect to type-2, type-3, and type-4 events.

ATRIB(2)	Not used.
ATRIB(3)	The model number associated with a particular lot.
ATRIB(4) to ATRIB(7)	Not used.

Section 2

This section defines the remainder of the variables that are used in the simulation program. Those variables designated with an "@" are the information system configuration parameters that are changed for each simulation test.

BILL(I,J)	This array is the bill of materials and associated cost and production data. The integer I indicates the part number of a particular part. The integer J identifies the Jth attribute of the Ith part. The cost and production values in the bill of materials are based on the respective average values for the past year.
BILL(I,J) J=1, 19	The number of parts of the Ith type used in making the Jth instrument model.
BILL(I,20)	The sum of the labor and material costs required to make the Ith part. Overhead is included in the labor cost (dollars/part).
BILL(I,21)	The average daily rate of consumption of the Ith part (parts/day).
BILL(I,22)	The average setup time (minutes/batch) required for a batch of the Ith part.
BILL(I,23)	The number of men required to make a batch of the Ith part (men/batch).
BILL(I,24)	The number of parts to be made in a batch of the Ith part (parts/batch).
BILL(I,25)	The average rate of production for the Ith part (parts/day).

BILL(I,26) The initial buffer level for the Ith part (20-day supply of parts).

BILL(I,27) The current number of parts of the Ith type that is on hand (initially, approximately a 35-day supply).

BILL(I,28) The current production status of the Ith part.

0.0	no current parts order
1.0	part is on order
2.0	order is in backorder file

BILL(I,29) The current production priority of the Ith part.

0.0	stock is above the buffer level
1.0	stockout; part is in demand
2.0	stockout; no immediate demand for part
3.0	stock is below the buffer level

BILL(I,30) The sum of the interest cost and storage cost associated with the Ith part (dollars/day).

DELAY@ The time (in days) required by the proposed information system to collect and process information for a report about the inventory.

EST The number of parts of a particular type that has been estimated to be on hand.

IPROB(N) An array of 1,000 cells which represents the instrument demand distribution. Each cell contains an instrument model number. The number of cells having the same model number is 1000 x X(J).

ISEED Random number generating seed.

LOT The number which has been assigned to the last lot that was created.

NPROD The cumulative number of instruments that have been produced.

NUM The total number of parts considered in the model.

PARAM(1,I) A GASP II variable which specifies the parameters of the function RNORM(1). RNORM(1) produces a random normal deviate from a distribution with parameters:

PARAM(1,1)	The mean of the distribution.
PARAM(1,2)	The minimum value.
PARAM(1,3)	The maximum value.
PARAM(1,4)	The standard deviation.

RNORM(1) is used to obtain the value of EST. The values stored in PARAM(1,I) are changed each time RNORM(1) is called.

PARAM(2,I) — This array is used in the same manner as PARAM (1,I) except that it is used in reference to RNORM(2) to determine the amount of time that the shop foreman will take in preparing a parts order and getting it to the production scheduling center.

PTIME — The time (in days) required to make a batch of a particular part. This does not include the setup time.

REACT — The time required for the shop foreman to start making a parts order after he has been notified that a part is below the buffer level.

SIG@ — The fraction of the number of parts which are currently on hand, which will be used as the standard deviation of the distribution of estimates that are made by the proposed information system. This variable determines the accuracy of the proposed information system.

STORE — The current carrying cost (dollars/day) of the entire finished parts inventory.

TNOW — The current simulated time in days.

TOTINV — The current dollar value of the entire finished parts inventory.

XINTER@ — The interval between successive checks of the finished parts inventory by the proposed information system.

X(J) — A fraction equal to:

$$\frac{\text{Number of Model J instruments produced annually}}{\text{Total number of instruments produced annually}}$$

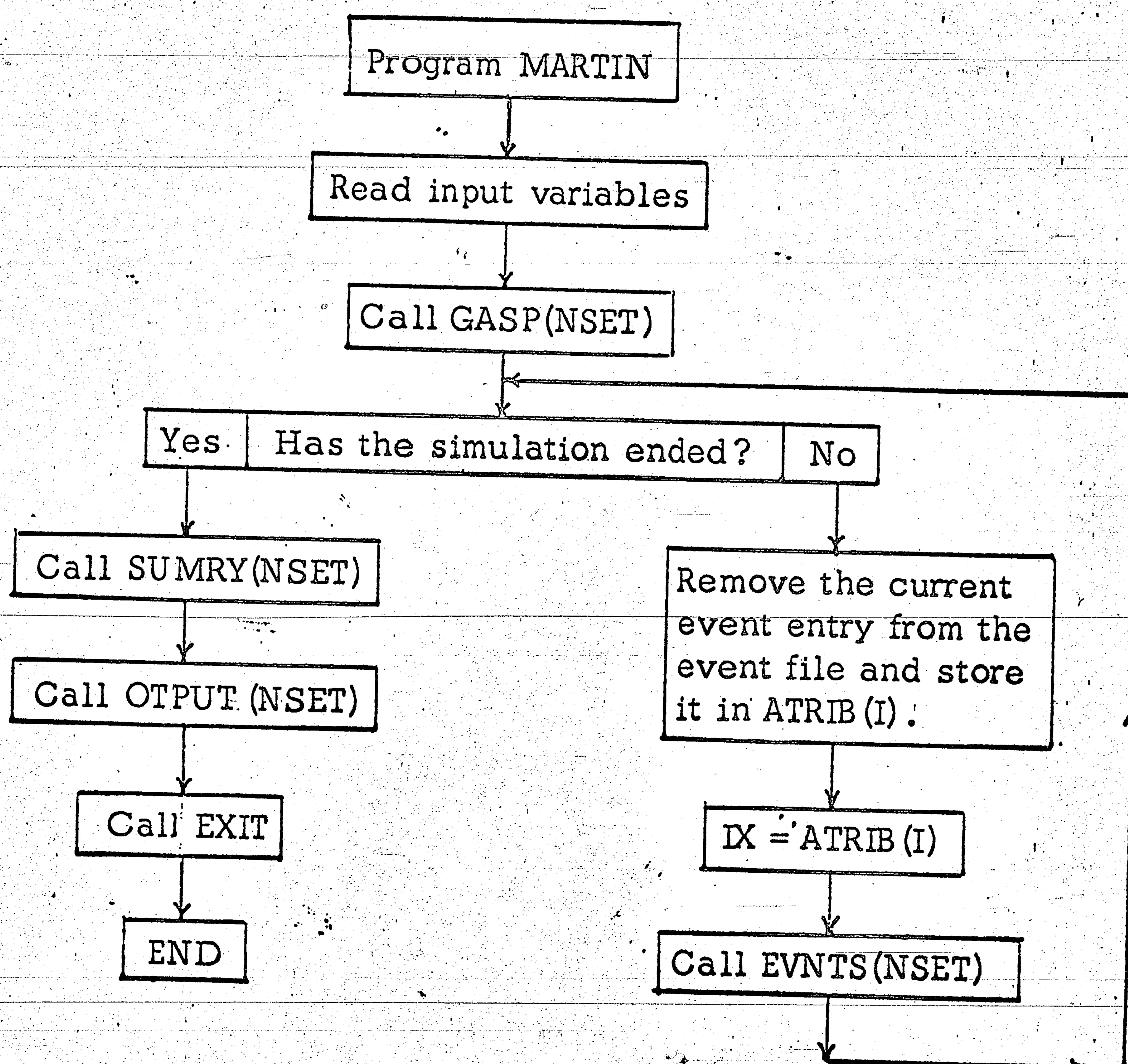
APPENDIX II

SIMULATION PROGRAM AND FLOW CHARTS

This appendix contains the subroutines of the simulation program and abbreivated flow charts of each subroutine.

FIGURE 10

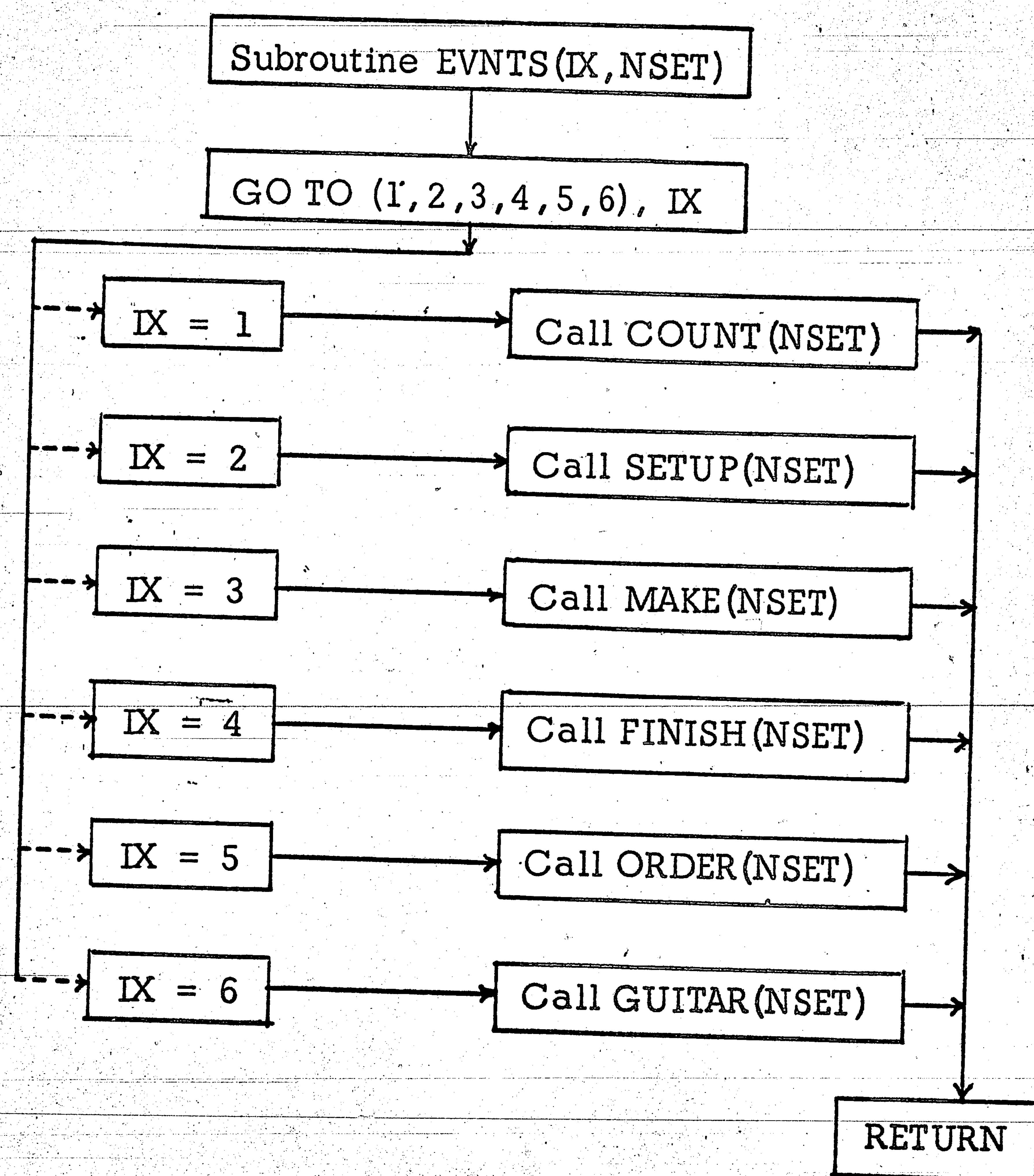
General Flow Chart of the Simulation Program



```
      PROGRAM MARTIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION NSET(12,400)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      NCRDR=5
      NPRNT=6
      NPROD=0
      LOT=0
      READ(NCRDR,10)   XMEN,SIG,DELAY,XINTER,STORE,TOTINV,NQUANT
   10 FORMAT(6F10.2,I10)
      WRITE(NPRNT,15) XMEN,SIG,DELAY,XINTER,STORE,TOTINV,NQUANT
   15 FORMAT(15X,*XMEN          SIGMA          DELAY     XINTER       STORE      TOTINV
     1      NQUANT*,/,10X,6F10.3,I10,////)
      READ(NCRDR,20)  (X(I),I=1,20)
   20 FORMAT(10F8.2,/,10F8.2)
      K=1
      DO 40 J=1,20
      M=X(J)*1000.0
      KK=K+M
      DO 30 N=K,KK
   30 IPROB(N)=J
   40 K=KK+1
      NUM=1
   45 READ(NCRDR,50) I, (BILL(NUM,J), J=1,30)
   50 FORMAT(I4,19F4.1,/,6F12.5,/,4F9.2,F16.7)
      IF(I .EQ. 0) GO TO 60
      NUM=NUM+1
      GO TO 45
   60 CONTINUE
      NUM=NUM-1
      CALL GASP(NSET)
      CALL EXIT
      END
```

FIGURE 11

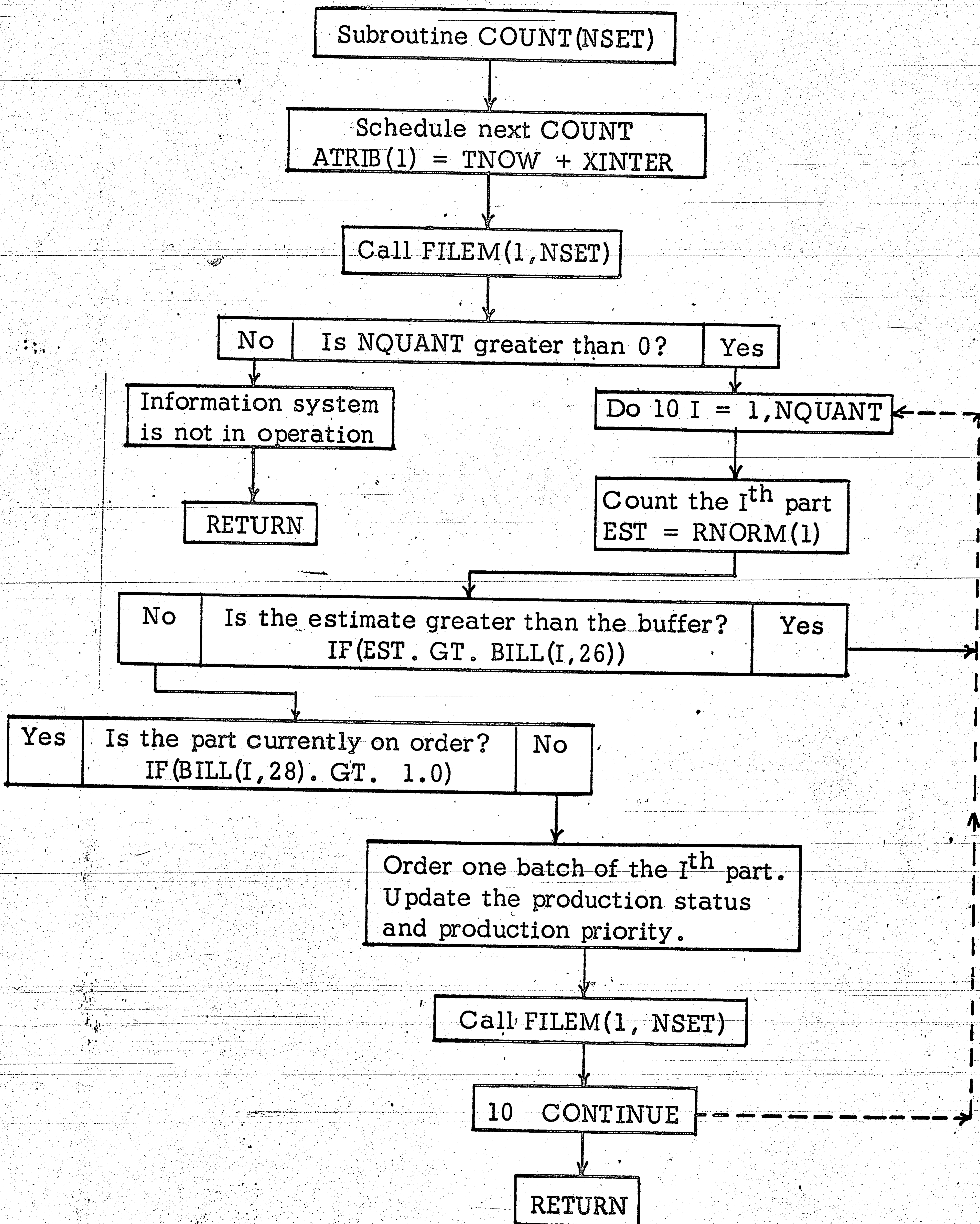
Flow Chart of Subroutine EVNTS



```
      SUBROUTINE EVNTS(IX,NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      GO TO (1,2,3,4,5,6),IX
    1 CALL COUNT(NSET)
      RETURN
    2 CALL SETUP(NSET)
      RETURN
    3 CALL MAKE(NSET)
      RETURN
    4 CALL FINISH(NSET)
      RETURN
    5 CALL ORDER(NSET)
      RETURN
    6 CALL GUITAR(NSET)
      RETURN
      END
```

FIGURE 12

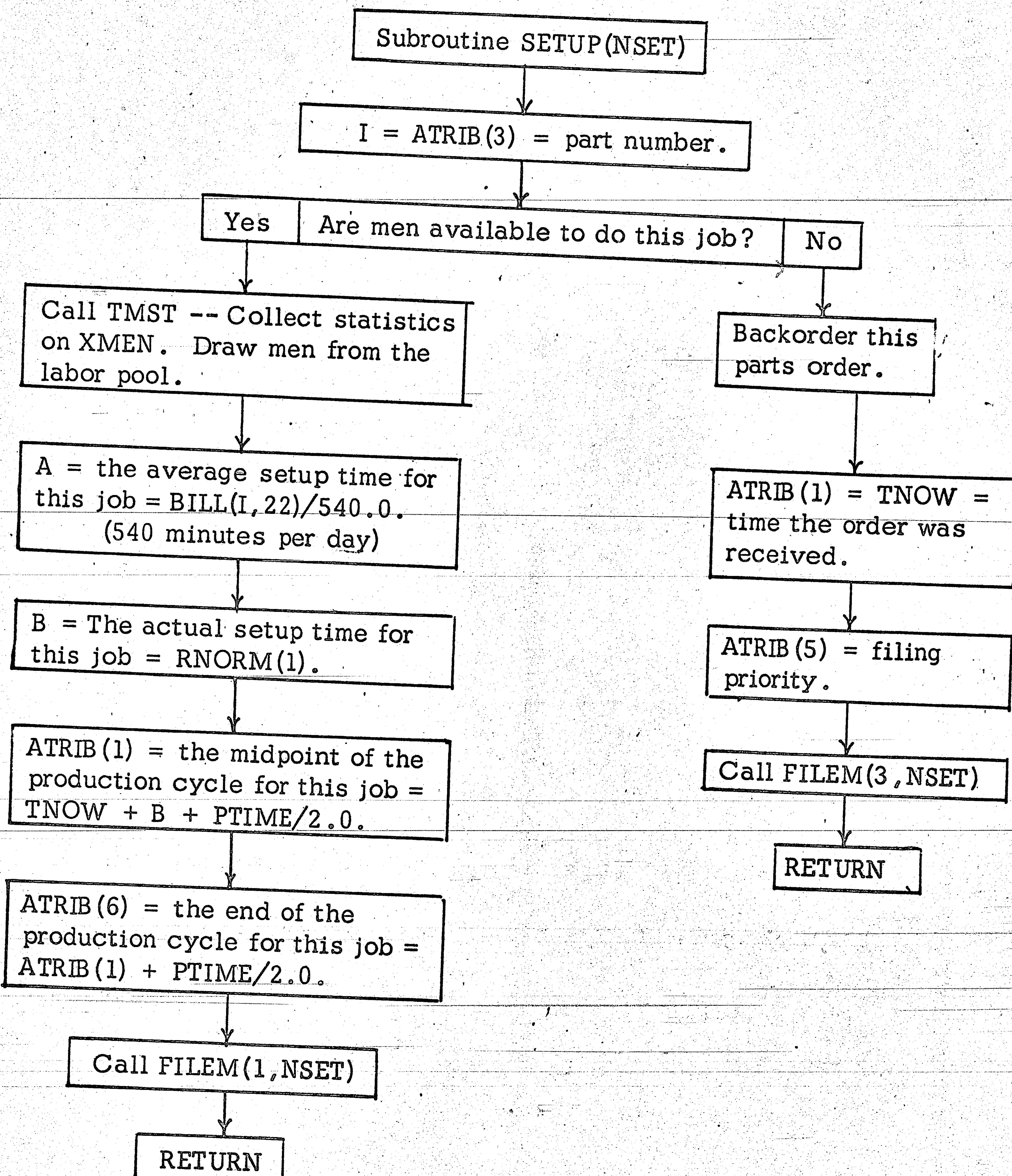
Flow Chart of Subroutine COUNT



```
      SUBROUTINE COUNT(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      ATRIB(1)= TNOW+XINTER
      CALL FILEM(1,NSET)
      IF(NQUANT. GT. 0) GO TO 5
      RETURN
    5 DO 10 I=1,NQUANT
      A=BILL(I,27)
      PARAM(1,1)=A
      B=SIG*A
      PARAM(1,2)=A-3.0*B
      PARAM(1,3)=A+3.0*B
      PARAM(1,4)=B
      EST=RNORM(1)
      IF(EST. GT. BILL(I,26)) GO TO 10
      IF(BILL(I,28). GT. 1.0) GO TO 10
      REACT=RNORM(2)
      ATRIB(1)=TNOW+DELAY+REACT
      ATRIB(2)=2.0
      ATRIB(3)=I
      ATRIB(4)=BILL(I,24)
      BILL(I,28)=1.0
      IF(BILL(I,29). EQ. 1.0) GO TO 20
      IF(EST. LT. BILL(I,21)) GO TO 19
      BILL(I,29)=3.0
      GO TO 20
   19 BILL(I,29)=2.0
   20 ATRIB(5)=BILL(I,29)
      CALL FILEM(1,NSET)
      BILL(I,28)=1.0
   10 CONTINUE
      RETURN
      END
```

FIGURE 13

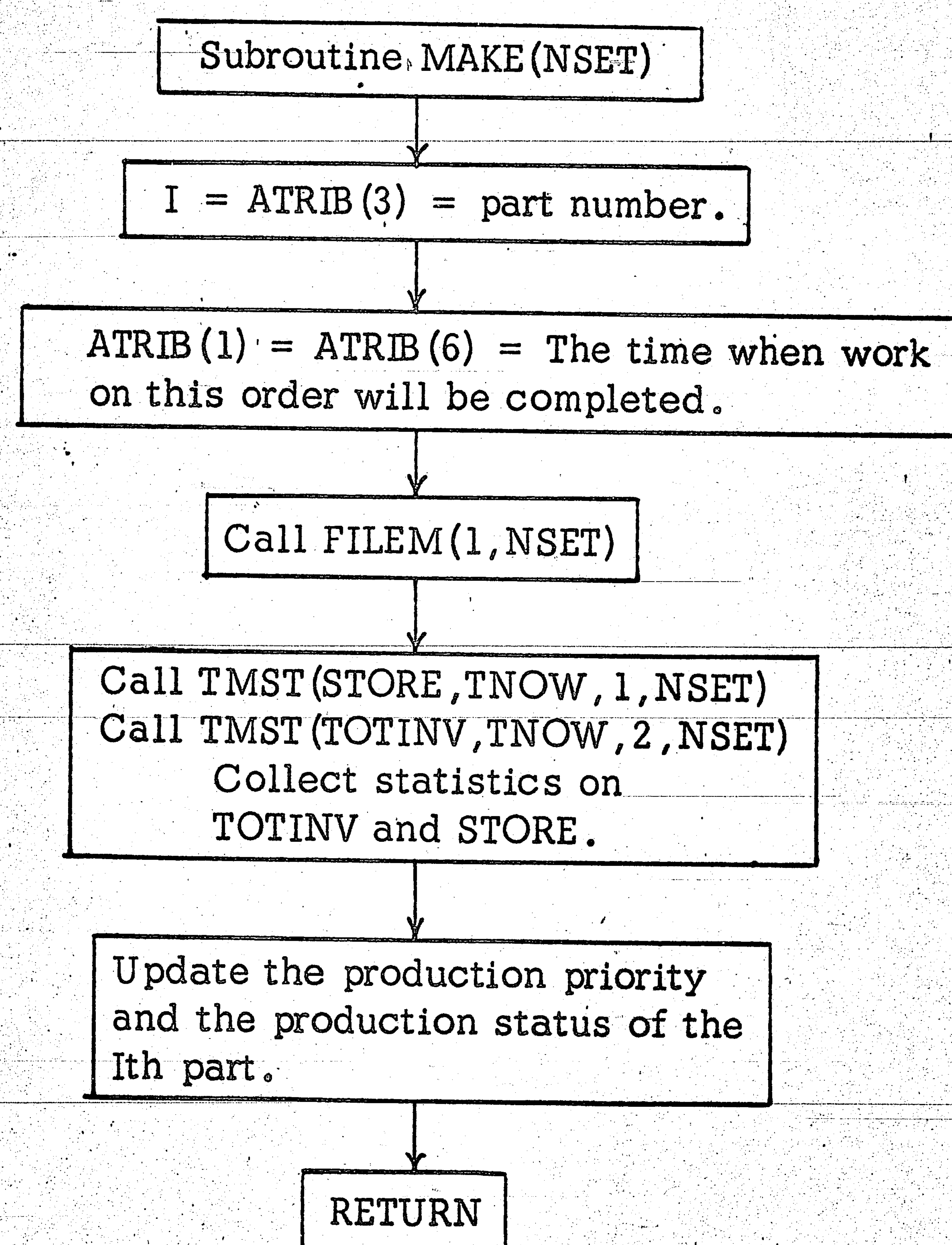
Flow Chart of Subroutine SETUP



```
      SUBROUTINE SETUP(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPPNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      I=ATRIB(3)
      IF(XMEN. LT. BILL(I,23))GO TO 25
      CALL TMST(XMEN,TNOW,3,NSET)
      XMEN=XMEN-BILL(I,23)
      A=BILL(I,22)/540.0
      PARAM(1,1)=A
      PARAM(1,2)=A*0.6
      PARAM(1,3)=A*1.4
      PARAM(1,4)=A*0.2
      B=RNORM(1)
      ATRIB(4)=BILL(I,24)
      PTIME=ATRIB(4)/BILL(I,25)
      ATRIB(1)=TNOW+B+PTIME/2.0
      ATRIB(2)=3.0
      ATRIB(6)=ATRIB(1)+PTIME/2.0
      CALL FILEM(1,NSET)
      RETURN
   25 ATRIB(1)=TNOW
      ATRIB(5)=BILL(I,29)*TNOW+DRAND(ISEED)/10.0
      ATRIB(7)=BILL(I,29)
      CALL FILEM(2,NSET)
      BILL(I,28)=2.0
   30 RETURN
      END
```

FIGURE 14

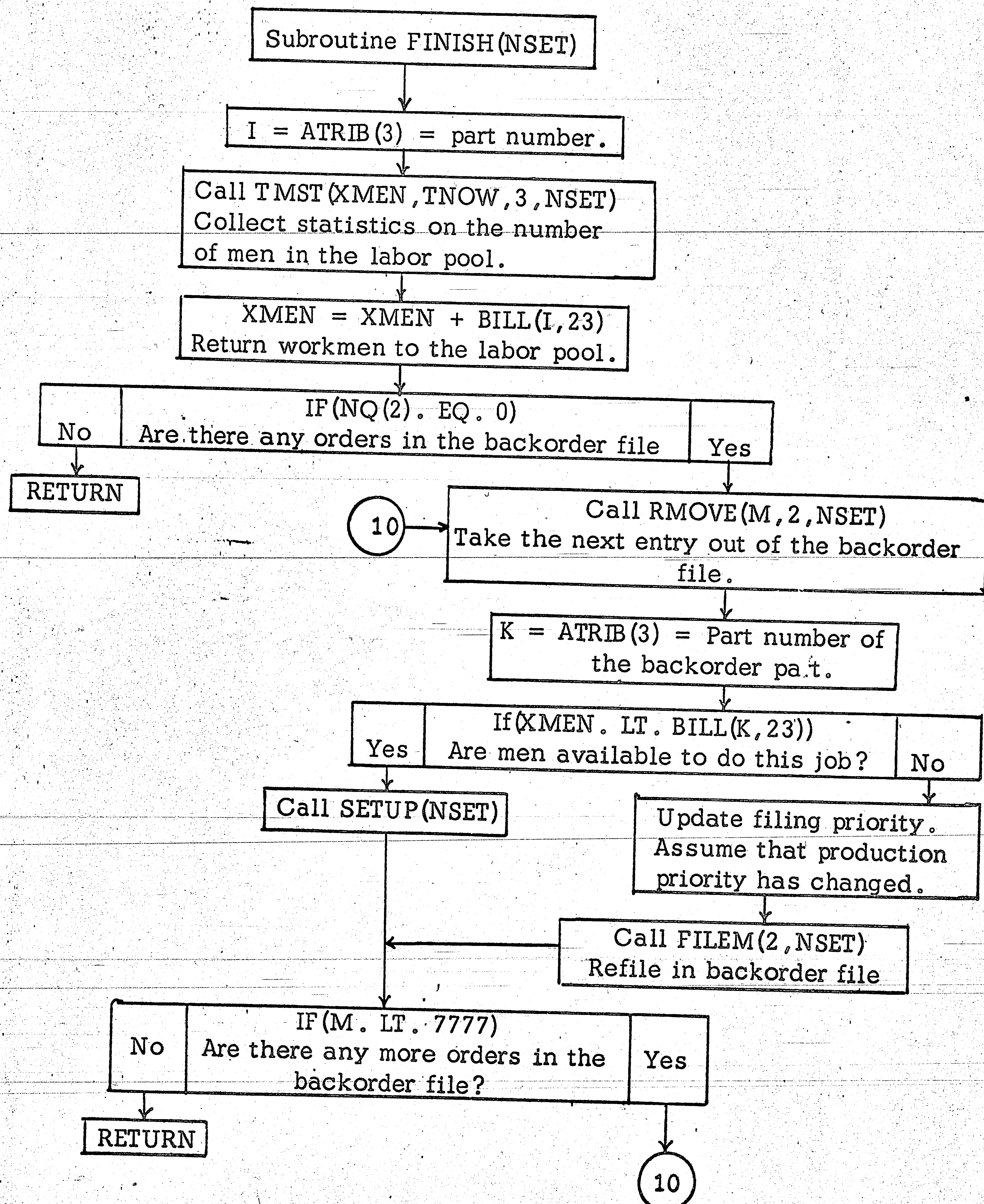
Flow Chart for Subroutine MAKE



```
      SUBROUTINE MAKE(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,       1
     2TBEG,TFIN,MXX,NPRNT,NCRDP,NEP,VNQ(100)                           2
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,  3
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40, 4
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR   5
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)  6
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      I=ATRIB(3)
      ATRIB(1)=ATRIB(6)
      ATRIB(2)=4.0
      CALL FILEM(1,NSET)
      CALL TMST(STORE ,TNOW,1,NSET)
      CALL TMST(TOTINV,TNOW,2,NSET)
      TOTINV=TOTINV+ATRIB(4)*BILL(I,20)
      STORE=STORE+ATRIB(4)*BILL(I,30)
      BILL(I,27)=BILL(I,27)+ATRIB(4)
      IF(BILL(I,27). GE. BILL(I,26)) BILL(I,29)=0.0
      IF(BILL(I,27). LT. BILL(I,26)) BILL(I,29)=3.0
      BILL(I,28)=0.0
      RETURN
      END
```

FIGURE 15

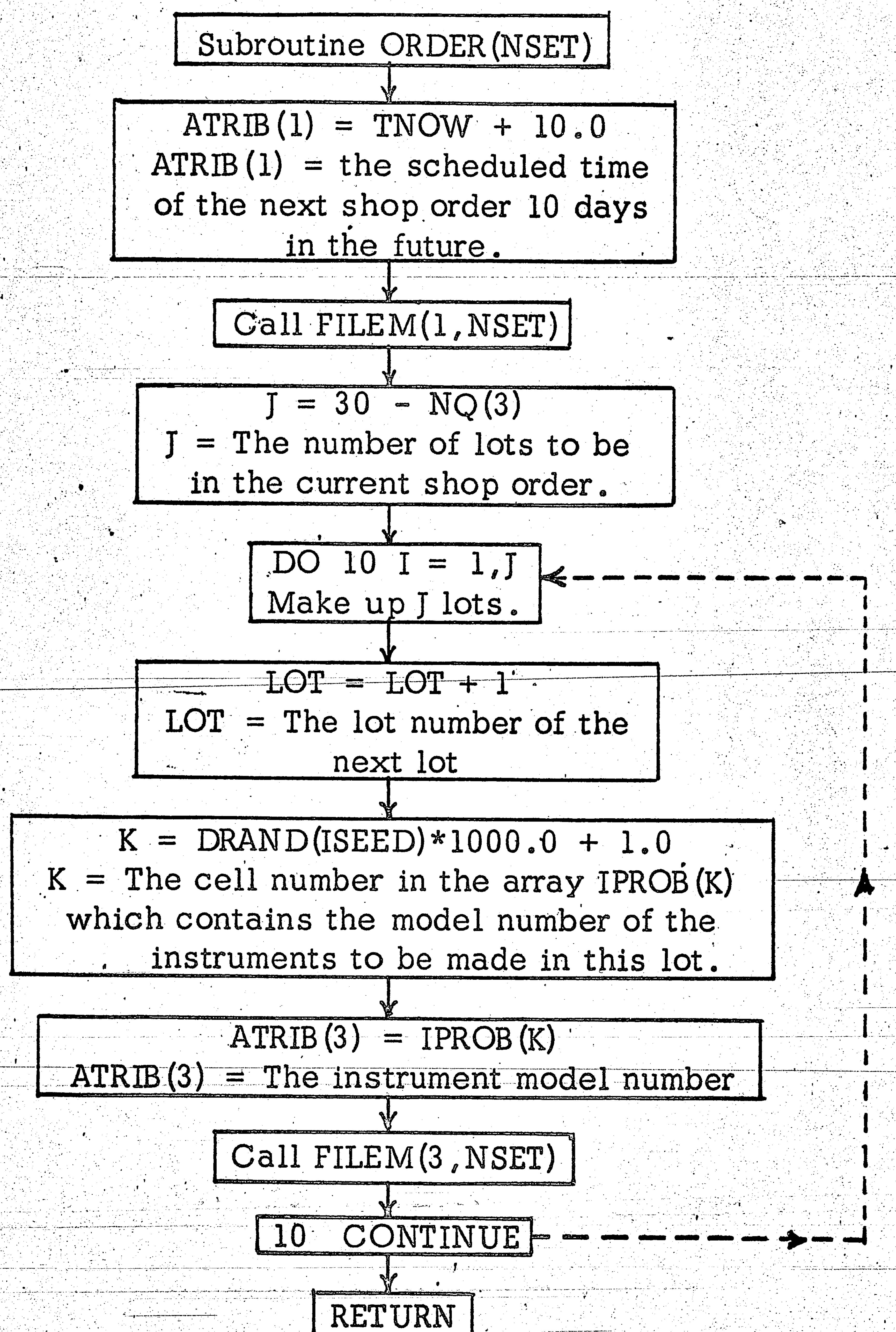
Flow Chart for Subroutine Finish



```
      SUBROUTINE FINISH(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NCRPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      IXX=0
      I=ATRIB(3)
      CALL TMST(XMEN,TNOW,3,NSET)
      XMEN=XMEN+BILL(I,23)
      IF(NQ(2). EQ. 0) GO TO 30
      M=MFE(2)
   10 MM=NSET(MX,M)
      CALL RMOVE(M,2,NSET)
      M=MM
      IXX=IXX+1
      K=ATRIB(3)
      IF(XMEN. LT. BILL(K,23)) GO TO 15
      CALL SETUP(NSET)
      GO TO 20
   15 IF(BILL(K,29). LT. ATRIB(7)) 19,16
   19 ATRIB(7)=BILL(K,29)
      ATRIB(5)=BILL(K,29)*ATRIB(1)+DRAND(ISEED) /10.0
   16 CALL FILEM(2,NSET)
      IF(IXX. GT. (NQ(2)+2)) GO TO 30
   20 IF(M. LT. 7777) GO TO 10
   30 RETURN
      END
```

FIGURE 16

Flow Chart for Subroutine ORDER



```
      SUBROUTINE ORDER(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,          1
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)                              2
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,    3
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,   4
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR     5
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)  6
     1,STORE,ILAST,XINTER,TOTINV,NPROD,NQUANT
      ATRIB(1)=TNOW+10.0
      CALL FILEM(1,NSET)
      J=30-NQ(3)
      IF(J. LT. 1) GO TO 20
      DO 10 I=1,J
      LOT=LOT+1
      ATRIB(1)=LOT
      K=DRAND(ISEED)*1000.0+1.0
      ATRIB(3)=IPROB(K)
      CALL FILEM(3,NSET)
   10 CONTINUE
   20 RETURN
      END
```

FIGURE 17

Flow Chart for Subroutine GUITAR

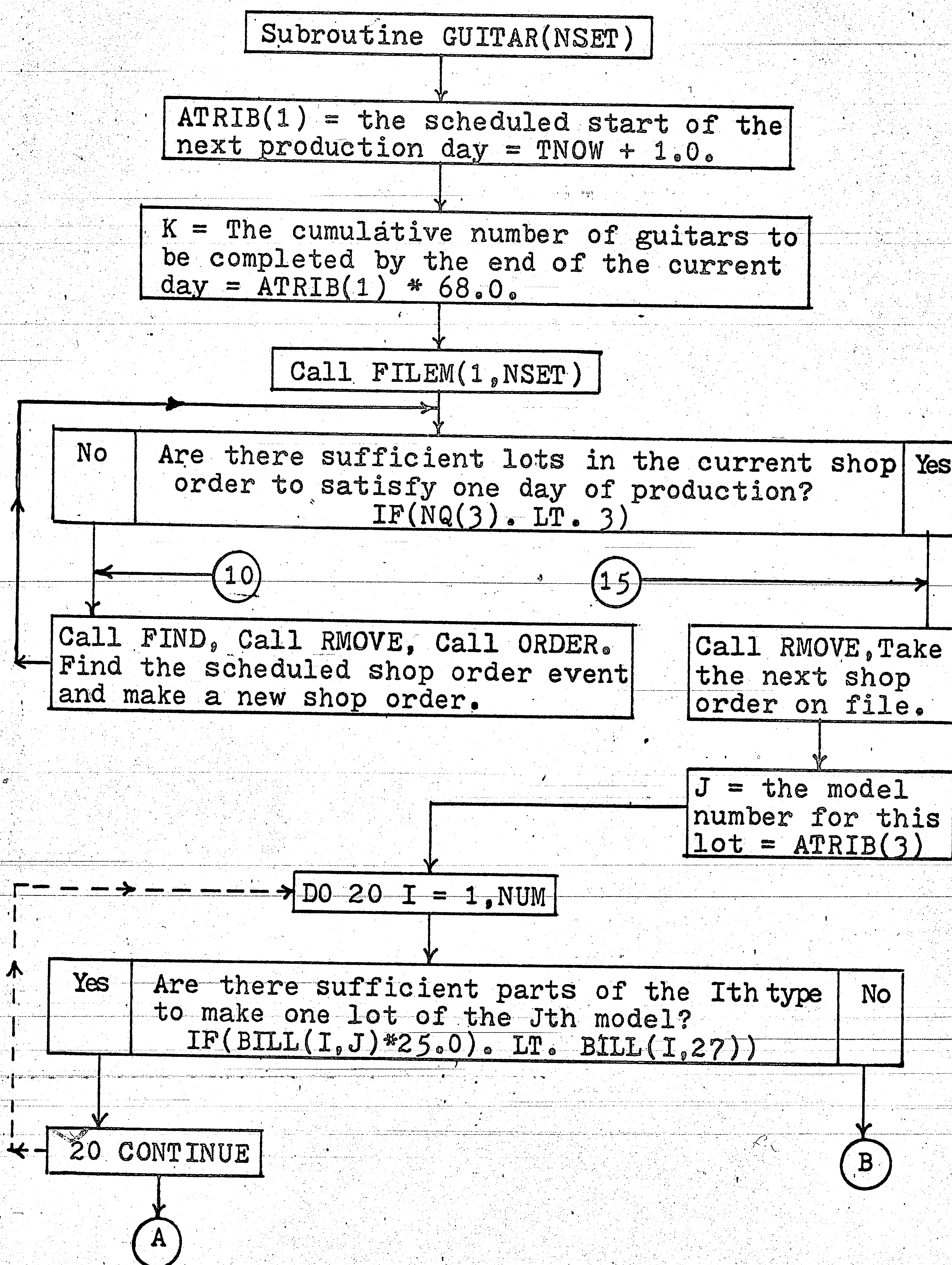


Figure 17. (continued)

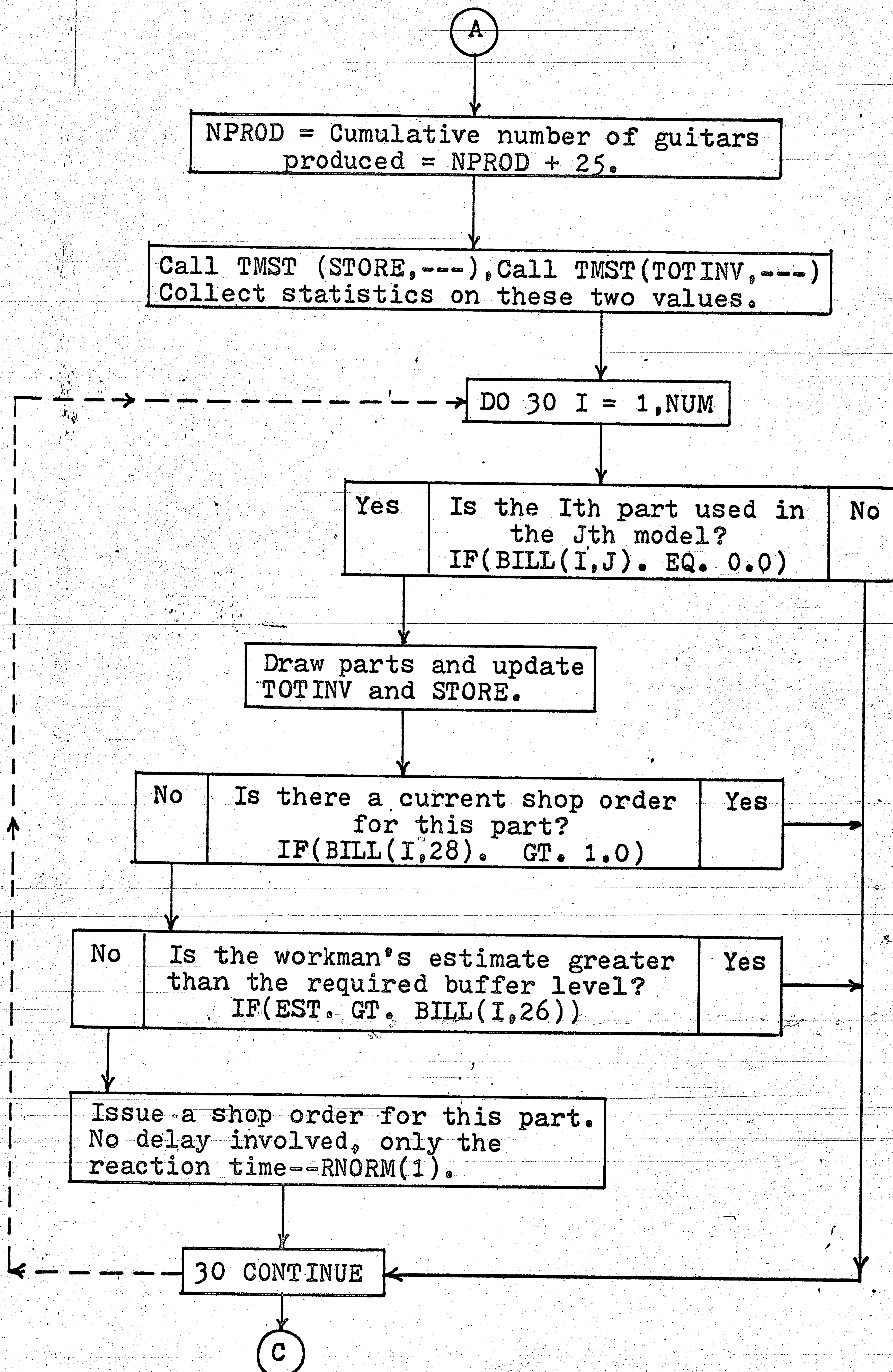
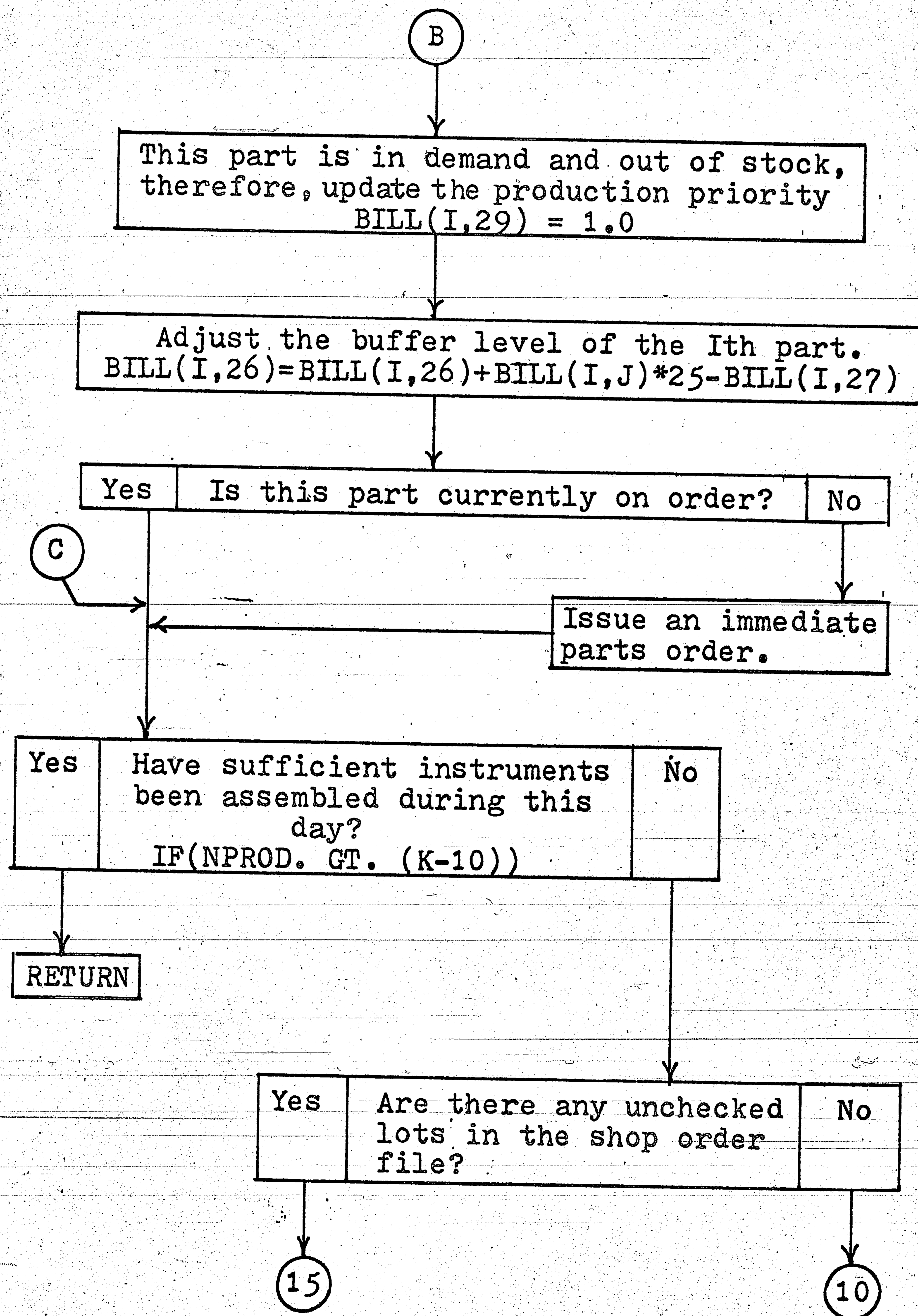


Figure 17. (continued)



```
      SUBROUTINE GUITAR(NSET)
      DIMENSION NSET(12,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(100)
      COMMON ATRIB(10),ENQ(100),INN(100),JCELS(10,32),KRANK(100),JCLR,
     1MAXNQ(100),MFE(100),MCL(100),MLE(100),NCELS(10),NQ(100),PARAM(40,
     24),QTIME(100),SSUMA(30,5),SUMA(30,5),NAME(6),NPROJ,MON,NDAY,NYR
      COMMON BILL(100,30),XMEN,NUM,SIG,INTER,DELAY,IPROB(1000),LOT,X(20)
     1,STORE,TLAST,XINTER,TOTINV,NPROD,NQUANT
      KKK=0
      ATRIB(1)=TNOW+1.0
      K=ATRIB(1)*60.0
      CALL FILEM(1,NSET)
    5 IF(NQ(3). LT. 3) GO TO 10
      IF(KKK. EQ. 2) GO TO 45
      M=MFE(3)
   15 MM=NSET(MX,M)
      CALL RMOVE(M,3,NSET)
      M=MM
      J=ATRIB(3)
      H=ATRIB(3)
      DO 20 I=1,NUM
      IF((BILL(I,J)*25.0). LT. BILL(I,27))GO TO 20
      BILL(I,29)=1.0
      BILL(I,26)=BILL(I,26)+BILL(I,J)*25.0-BILL(I,27)
      CALL FILEM(3,NSET)
      IF(BILL(I,28). GT. 1.0) GO TO 40
      ATRIB(1)=TNOW
      ATRIB(3)=I
      CALL SETUP(NSET)
      GO TO 40
   20 CONTINUE
      CALL HISTO(H,1.5,1.0,1)
      NPROD=NPROD+25
```

```
      CALL TMST(STORE ,TNOW,1,NSET)
      CALL TMST(TOTINV,TNOW,2,NSET)
      DO 30 I=1,NUM
      IF(BILL(I,J). EQ. 0.0) GO TO 30
      BILL(I,27)=BILL(I,27)-25.0*BILL(I,J)
      TOTINV=TOTINV-25.0*BILL(I,29)*BILL(I,J)
      STORE=STORE-25.0*BILL(I,30)*BILL(I,J)
      IF(BILL(I,28). GT. 0.0) GO TO 30
      PARAM(1,1)=BILL(I,27)
      PARAM(1,4)=0.2*BILL(I,27)
      PARAM(1,2)= BILL(I,27)-2.0*PARAM(1,4)
      PARAM(1,3)= BILL(I,27)+2.0*PARAM(1,4)
      EST=RNORM(1)
      IF(EST. GT. BILL(I,26))GO TO 30
      ATRIB(1)=TNOW+RNORM(2)
      ATRIB(2)=2.0
      ATRIB(3)=I
      ATRIB(4)=BILL(I,24)
      BILL(I,28)=1.0
      CALL FILEM(1,NSET)
30    CONTINUE
40    IF(NPROD. GT. (K-10)) GO TO 50
      IF(M. LT. 7777) GO TO 15
      KKK=KKK+1
      CALL COLCT(1,1,NSET)
10    CALL FIND(5.0,5,1,2,KCOL,NSET)
      CALL RMOVE(KCOL,1,NSET)
      CALL ORDER(NSET)
      GO TO 5
45    CONTINUE
50    RETURN
      END
```

APPENDIX III

SIMULATION PROGRAM INPUT DATA

This appendix lists the four basic groups of input data for the simulation program.

GROUP-A DATA. System Parameters.

Format: (6F10.2,I10)

Number of cards: 1

Variables:

Field 1. XMEN = 19.0

Field 2. SIG = See Figure 6.

Field 3. DELAY = See Figure 6.

Field 4. XINTER = See Figure 6.

Field 5. STORE = 22.91

Field 6. TOTINV = 23476.72

Field 7. NQUANT = See Figure 6.

GROUP-B DATA. Instrument Demand Parameters.

Format: (10F8.2,/,10F8.2)

Number of cards: 2

Variables:

Field J. X(J) = See Figure 3.

Note: The sum of all X(J) must equal exactly 1.000.

<u>GROUP-C DATA.</u> Bill of Materials.

Format: (I4,19F4.1,/,6F12.5,/,4F9.2,F16.7)

Number of cards: Three cards per part, less than or equal to 100 parts.

Variables:

Field 1. I = Part number

Field J+1. (BILL(I,J),J=1,30) = See enclosed table.

Note: This group of data is followed by three blank cards.

<u>GROUP-D DATA.</u> GASP II Type-6 Parameters.

Format: (4F10.5)

Number of cards: 2

Variables:

Card 1. Blank--values assigned by the program.

Card 2.

Field 1. PARAM(2,1) = 1.0

Field 2. PARAM(2,2) = 0.5

Field 3. PARAM(2,3) = 1.5

Field 4. PARAM(2,4) = 0.2

PART (I)	PARAMETER (J) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0
2	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
3	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
6	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
8	0	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
11	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
12	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0
13	2	2	2	2	2	4	4	4	4	4	4	4	4	4	0	0	4	4	0
14	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
16	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	2	2	2	0	2	0	2	2	0	0	0	2	0
18	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0
19	0	0	0	0	0	0	0	0	2	0	2	0	0	0	2	2	0	0	0
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
21	0	0	0	0	0	0	2	2	2	0	2	0	0	0	2	2	0	0	0
22	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0

FIGURE 18. Bill of Materials and Initial Inventory

PART (I)	PARAMETER (J) 20	21	22	23	24	25	26	27	28	29	30
1	1.9	51.7	10.0	2.0	205.3	73.9	1033.6	1045.8	.0	3.0	.00180
2	2.2	41.3	200.0	2.0	850.7	144.3	826.2	884.5	.0	3.0	.00217
3	3.6	22.4	150.0	3.5	425.6	96.6	448.8	591.4	.0	3.0	.00359
4	3.8	14.5	150.0	3.5	342.9	89.3	289.7	657.7	.0	3.0	.00376
5	3.9	12.6	200.0	3.5	363.5	83.4	252.3	319.0	.0	3.0	.00393
6	2.2	16.1	200.0	2.0	568.4	144.3	322.0	532.3	.0	3.0	.00217
7	.5	67.3	65.0	2.2	1395.5	308.2	1346.0	1392.8	.0	3.0	.00045
8	3.6	7.3	150.0	3.5	258.0	96.6	146.6	195.5	.0	3.0	.00359
9	.6	31.2	62.0	2.0	855.6	282.0	624.0	740.7	.0	3.0	.00057
10	25.0	.7	300.0	4.0	42.7	17.1	14.0	29.7	.0	3.0	.02548
11	.4	41.3	30.0	1.0	805.5	243.6	826.2	1281.0	.0	3.0	.00040
12	.3	53.9	30.0	1.0	1046.4	289.6	1078.5	1835.6	.0	3.0	.00030
13	.1	242.8	25.0	2.0	5053.1	2521.6	4856.6	8536.6	.0	3.0	.00005
14	3.9	3.5	150.0	3.5	172.6	83.4	69.5	154.9	.0	3.0	.00393
15	2.0	15.6	10.0	2.0	131.9	73.9	312.4	484.1	.0	3.0	.00185
16	2.0	6.4	200.0	2.0	388.9	144.3	128.2	287.7	.0	3.0	.00195
17	.1	88.9	80.0	2.3	3691.8	1556.7	1777.5	3580.1	.0	3.0	.00012
18	4.1	2.4	200.0	3.5	161.9	77.6	47.5	89.9	.0	3.0	.00412
19	.2	58.0	90.0	2.0	2731.6	931.9	1160.1	2021.9	.0	3.0	.00016
20	.1	67.3	90.0	2.0	3303.3	1224.8	1346.0	2561.3	.0	3.0	.00012
21	.1	62.4	45.0	1.0	2301.8	595.4	1247.9	1536.1	.0	3.0	.00012
22	3.9	2.0	200.0	3.5	152.6	83.0	40.3	70.8	.0	3.0	.00394
23	2.9	2.6	200.0	3.5	195.0	83.3	51.4	101.7	.0	3.0	.00301
24	2.0	3.5	200.0	2.0	289.5	144.3	69.5	106.8	.0	3.0	.00194
25	.1	54.7	1.0	1.0	325.7	1004.7	1093.7	1548.4	.0	3.0	.00012

PART (I) / PARAMETER (J)

PART (I)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
28	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
31	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1	0
32	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0
33	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
34	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
36	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0
37	1	2	0	2	0	2	0	0	0	0	0	0	2	2	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	2	2	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
40	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
41	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	2	0	0
44	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0
45	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0
46	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
49	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0

PART (I)	PARAMETER (J) 20	21	22	23	24	25	26	27	28	29	30
26	.1	67.3	10.0	1.0	1306.4	714.4	1346.0	2230.3	.0	3.0	.00009
27	.5	12.6	30.0	1.0	435.7	200.9	252.3	302.8	.0	3.0	.00045
28	.1	52.6	10.0	1.0	1114.9	706.6	1052.0	2408.5	.0	3.0	.00010
29	.6	8.0	62.0	2.0	449.5	282.0	160.5	390.5	.0	3.0	.00057
30	.6	10.1	62.0	2.0	502.9	282.0	202.2	504.4	.0	3.0	.00057
31	.1	44.5	80.0	2.3	2758.8	1556.7	890.8	1393.9	.0	3.0	.00011
32	.1	43.5	50.0	2.5	2339.3	1710.1	870.1	1254.9	.0	3.0	.00010
33	.3	13.4	30.0	1.0	560.9	289.6	267.5	420.2	.0	3.0	.00029
34	.6	8.2	62.0	2.0	470.2	282.0	164.8	320.6	.0	3.0	.00054
35	.2	25.2	90.0	2.0	1829.5	931.9	504.6	773.7	.0	3.0	.00016
36	.1	37.7	80.0	2.3	2533.9	1556.7	753.0	1274.9	.0	3.0	.00011
37	.1	33.1	45.0	1.0	1712.1	595.4	661.2	1228.8	.0	3.0	.00012
38	.1	29.6	45.0	1.0	1624.8	595.4	592.4	836.7	.0	3.0	.00012
39	.6	4.6	62.0	2.0	341.8	282.0	91.8	160.5	.0	3.0	.00057
40	.2	18.8	90.0	2.0	1582.8	931.9	375.4	669.0	.0	3.0	.00016
41	.2	15.4	90.0	2.0	1435.3	931.9	307.6	601.0	.0	3.0	.00016
42	.4	6.4	30.0	1.0	358.0	279.6	128.2	151.6	.0	3.0	.00036
43	.1	20.4	80.0	2.3	1804.6	1556.7	408.8	412.3	.0	3.0	.00012
44	.0	53.9	15.0	1.0	2238.7	1837.1	1078.5	2603.7	.0	3.0	.00004
45	.1	14.8	80.0	2.3	1568.1	1556.7	296.2	565.2	.0	3.0	.00011
46	.1	13.4	80.0	2.3	1538.0	1556.7	267.5	326.4	.0	3.0	.00011
47	.1	12.6	1.0	1.0	165.8	1004.7	252.3	416.0	.0	3.0	.00011
48	.1	12.6	50.0	2.5	1270.8	1710.1	252.3	355.8	.0	3.0	.00010
49	.4	3.5	30.0	1.0	263.3	279.6	69.8	148.1	.0	3.0	.00036
50	.1	10.8	80.0	2.3	1367.7	1556.7	216.1	225.2	.0	3.0	.00011

PART (I)	PARAMETER (J) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
51	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	3	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0
57	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	2	0	2	0	0	0	0	2	0	2	0	0	0	0	0	0	0
62	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
65	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
71	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PART (I)	PARAMETER (J) 20	21	22	23	24	25	26	27	28	29	30
51	.4	3.5	30.0	1.0	271.9	306.2	69.5	114.7	.0	3.0	.00034
52	.2	7.0	90.0	2.0	970.6	931.9	139.5	213.2	.0	3.0	.00016
53	.1	9.4	80.0	2.3	1289.7	1556.7	187.7	245.3	.0	3.0	.00011
54	.1	10.4	50.0	1.0	1260.1	945.6	208.5	227.5	.0	3.0	.00008
55	.1	12.6	45.0	1.0	1074.3	595.4	252.3	450.2	.0	3.0	.00012
56	.1	6.9	45.0	1.0	800.9	595.4	139.0	262.2	.0	3.0	.00012
57	.6	2.6	62.0	2.0	264.9	282.0	51.4	116.1	.0	3.0	.00054
58	.6	1.6	62.0	2.0	212.3	282.0	32.9	68.2	.0	3.0	.00054
59	.2	4.4	90.0	2.0	771.1	931.9	87.9	184.1	.0	3.0	.00016
60	.2	4.4	90.0	2.0	771.1	931.9	87.9	214.1	.0	3.0	.00016
61	.1	6.9	80.0	2.3	1098.1	1556.7	139.0	176.0	.0	3.0	.00011
62	.1	5.1	80.0	2.3	911.8	1556.7	102.7	170.3	.0	3.0	.00012
63	.1	5.1	80.0	2.3	911.8	1556.7	102.7	108.4	.0	3.0	.00012
64	.0	13.4	15.0	1.0	1126.5	1837.1	267.5	377.2	.0	3.0	.00004
65	.1	6.0	50.0	2.5	881.4	1710.1	120.9	176.1	.0	3.0	.00010
66	.1	5.1	50.0	2.5	812.5	1710.1	102.7	159.1	.0	3.0	.00010
67	.1	6.9	50.0	1.0	1259.2	1260.8	139.0	234.5	.0	3.0	.00005
68	.6	.9	62.0	2.0	158.7	282.0	18.4	30.9	.0	3.0	.00054
69	.2	1.5	90.0	2.0	444.5	931.9	29.1	55.2	.0	3.0	.00016
70	.0	5.1	10.0	1.0	584.4	1692.1	102.8	180.6	.0	3.0	.00004
71	.1	3.5	50.0	1.0	730.0	945.6	69.5	136.7	.0	3.0	.00008
72	.1	3.5	50.0	1.0	747.2	945.6	69.5	103.9	.0	3.0	.00007
73	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	.0	3.0	-0.00000

APPENDIX IV

SAMPLE OUTPUT OF SIMULATION PROGRAM

This appendix contains a sample output of the simulation program and a discription of the output values.

PARAMETER NO. 1 = Current values of PARA(1,J)

PARAMETER NO. 2 = Input values of PARAM(2,J)

GENERATED DATA

CODE 1. = The number of lots for which parts were not available.

TIME GENERATED

CODE 1. = Summary statistics of the parameter STORE.

CODE 2. = Summary statistics of the parameter TOTINV.

CODE 3. = Summary statistics of the parameter XMEN.

Note: The data of interest in this section of the output is the first column (MEAN). These are the time integrated means of the parameters referenced above. The remainder of this section is the normal output of GASP II, but it is not used in this particular problem. There would appear to be an inconsistancy between the minimums and the means, however, the minmums are computed from non-integrated data.

GENERATED FREQUENCY DISTRIBUTION

CODE 1. = From left to right, the number of instrument lots of the J^{th} type that were made during the simulation.

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                        **GASP SUMMARY REPORT**

           SIMULATION PROJECT NO.    1  BY   MENGEL

           DATE  4/ 30/ 1970                    RUN NUMBER     2

      PARAMETER NO.     1          .1667        .1000        .2333        .0333
      PARAMETER NO.     2         1.0000        .5000       1.5000        .2000

                              **GENERATED DATA**
          CODE      MEAN        STD.DEV.       MIN.        MAX.      OBS.

           1              NO VALUES RECORDED

                           **TIME GENERATED DATA**
          CODE      MEAN        STD.DEV.       MIN.        MAX.      TOTAL TIME

           1      23.0477       13.4605      25.8379      37.0371     199.1284
           2   23619.9553    13791.9369   26541.9267   37883.8965     199.1284
           3       7.4501        5.8935        .2000      19.0000     199.6674

                 **GENERATED FREQUENCY DISTRIBUTIONS**
          CODE                       HISTOGRAMS

           1          10    8   16   11   13    5    8    1   90    9   85
                       2   55    4    4    2   59   26    0    0    0    0
```

FIGURE 19. **Sample Output**

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VITA

PERSONAL HISTORY

Name:	Larry L. Mengel, Major, USA
Place or Birth:	Stockertown, Pennsylvania
Birthdate:	September 21, 1940
Parents:	Martin E. Mengel (deceased) Mrs. Blanche S. Mengel
Wife:	Martha Ann
Children:	Stephanie Ann

EDUCATIONAL BACKGROUND

U. S. Military Academy B. S. 1962	1958 - 1962
Lehigh University M. S. in Industrial Engineering - 1970	1968 - 1970

PROFESSIONAL EXPERIENCE

United States Army, Armor Branch	1962 - ----